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SNAP/RADTRAD: Description of Models and Methods

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ABSTRACT

This report documents the use of the RADTRAD plugin to the SNAP Graphical User Interface (GUI) and the RADionuclide Transport and Removal and Dose Estimation analytical code (RADTRAD-AC) developed for the U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Reactor Research to estimate transport and removal of radionuclides and dose at selected receptors. The SNAP/RADTRAD along with the RADTRAD-AC code is used to estimate the radionuclide release from the containment using either the NRC TID-14844 or NUREG-1465 source terms and assumptions, or a user-specified table. In addition, the code can account for a reduction in the quantity of radioactive material released due to containment sprays, natural deposition, filters, and other engineered safety features. The code uses a combination of tables and numerical models of source term reduction phenomena to determine the time-dependent dose at user-specified locations for a given accident scenario. The code system also provides the inventory, decay chain, and dose conversion factor tables needed for the dose calculation. The SNAP/RADTRAD code can be used to assess occupational radiation exposures, typically in the control room; to estimate site boundary doses; and to estimate dose attenuation due to modification of a facility or accident sequence.

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In the contractor organizations, the contributions of Ken Jones of Applied Programming Technology who, along with his programming staff, develop and maintain the SNAP code are greatly appreciated.

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ABBREVIATIONS

APT	Applied Programming Technology
AptPlot	Applied Programming Technology plotting package
APWR	advanced pressurized-water reactor
Bq	Becquerels
BWR	boiling-water reactor
Ci	curie
CRDA	control rod drop accident
DCF	dose conversion factor
DE	dose equivalent
DE I-131	dose equivalent iodine 131
DE Xe-133	dose equivalent xenon 133
DF	decontamination factor
DBA-TID	design-basis accident based on TID-14844
DBA-AST	design-basis accident using NUREG-1465 (Regulatory Guide 1.183) models
EAB	exclusion area boundary
FGR	Federal Guidance Report
FHA	fuel handling accident
GUI	graphical user interface
HEPA	high-efficiency particulate air
LOCA	loss-of-coolant accident
LPZ	low population zone
MWth	megawatt thermal
NRC	U.S. Nuclear Regulatory Commission
ODE	ordinary differential equation
PWR	pressurized-water reactor
RCS	reactor coolant system
RADTRAD	RADionuclide Transport, Removal, And Dose Esitmation
RAMP	Radiation Protection Computer Code Analysis and Maintenance Program
REA	rod ejection accident
RG	Regulatory Guide
SI	International System of Units
SNAP	Symbolic Nuclear Analysis Package
Sv	Sieverts
TEDE	total effective dose equivalent
T/S	technical specification
XML	extensible markup language

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1.0 INTRODUCTION

The purpose of the Symbolic Nuclear Analysis Package/RADionuclide Transport and Removal and Dose Estimation (SNAP/RADTRAD) code is to determine the dose from a release of radionuclides during a design basis accident to the exclusion area boundary (EAB), the low population zone (LPZ), and the control room and other locations of interest. As radioactive material is transported through the containment, the user can account for sprays and natural deposition to reduce the quantity of radioactive material. Material can flow between buildings, from buildings to the environment, or into control rooms through high-efficiency particulate air (HEPA) filters, piping, or other connectors. Decay and in-growth of daughters can be calculated over time as the material is transported.

The focus of SNAP/RADTRAD is licensing analysis to show compliance with nuclear plant siting and control room dose limits for various loss-of-coolant accidents (LOCAs) and non-LOCA accidents. The RADTRAD code was originally developed by the Accident Analysis and Consequence Assessment Department at Sandia National Laboratories for the U.S. Nuclear Regulatory Commission (NRC) in 1997 as documented in NUREG/CR-6604, "RADTRAD: A Simplified Model for RADionuclide Transport and Removal and Dose Estimation," [1]. The code was revised to include a Visual Basic graphic user interface (GUI) for user convenience in 1999, which is described in NUREG/CR-6604, Supplement 1, "RADTRAD: A Simplified Model for RADionuclide Transport and Removal and Dose Estimation," [2]. Finally, NUREG/CR-6604, Supplement 2, "RADTRAD: A Simplified Model for RADionuclide Transport and Removal and Dose Estimation," [3] was published in 2002 discussing the testing of RADTRAD version 3.03.

The NRC decided to update RADTRAD by converting the code into JAVA and develop a RADTRAD plugin to interface with the SNAP graphical user interface (GUI). As part of the RADTRAD update, the analytical code that calculates the doses and generates the results was separated. Hence, SNAP with the RADTRAD plugin is used to develop models and prepare input which is then processed by the RADTRAD analytical code (RADTRAD-AC). The RADTRAD-AC then calculates the dose and generates the results. The combined package is referred to as SNAP/RADTRAD. Use of RADTRAD in the SNAP framework allows use of the SNAP features including the Model Editor for developing plant models. The Model Editor also provides tools for user input checking, for submitting and monitoring calculations, and for running multiple cases. The RADTRAD-AC generates data output files suitable for plotting with the Applied Programming Technology plotting package (APTPot).

As part of the development of the RADTRAD plugin for SNAP, the user documentation is being updated. This report provides the documentation for the use of SNAP/RADTRAD.

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2.0 INSTALLATION GUIDE

This section of the report discusses how to obtain and install SNAP/RADTRAD and the RADTRAD-AC codes.

2.1 Distribution

RADTRAD is distributed in two parts: the SNAP GUI with the RADTRAD plugin and the RADTRAD-AC. SNAP with the RADTRAD plugin is used for model development and input preparation while the RADTRAD-AC carries out the calculations and generates the results. SNAP with the RADTRAD plugin is maintained by Applied Programming Technologies, Inc. (APT) and the RADTRAD-AC analytical code is maintained by Information Systems Laboratory, Inc.

Directions for obtaining the SNAP GUI with the RADTRAD plugin and the RADTRAD-AC are available at the Radiation Protection Computer Code Analysis and Maintenance Program (RAMP) website. Current version information for SNAP with the RADTRAD plugin and RADTRAD-AC are also available at the RAMP website. Note that results plotting capability has been built into SNAP/RADTRAD using the AptPlot program.

The SNAP GUI with the RADTRAD plugin and the AptPlot program is available from the APT website. The RADTRAD-AC analytical code is available from the RAMP website. This code is designed to be compatible with the SNAP GUI with the RADTRAD plugin.

2.2 Hardware and Software Requirements

The SNAP GUI with the RADTRAD plugin (SNAP/RADTRAD) and the RADTRAD-AC code can be executed on any computer that supports Java applications. Any of the current generation of personal computers that can run the Java runtime environment is capable of running SNAP/RADTRAD and the RADTRAD analytical code. For a Windows computer, the Windows versions that can be used are Vista, Windows 7 and Windows 8. It should be noted that the following software is required:

- Java Standard Edition (SE) 6.0 or later. This package is currently available on http://www.oracle.com/technetwork/java/javase/downloads/index.html.
- SNAP GUI with the RADTRAD plugin code maintained by APT.
- RADTRAD-AC packaged separately, and distributed by RAMP.
- APTPlot – plotting package maintained by APT. For further details, see https://www.appliedprog.com/.

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Although not required, the jedit text editing program adds some user conveniences in SNAP/RADTRAD. This package is available from www.jedit.org.

2.3 Installation

Installation of SNAP is very similar to installation of any software package on a Windows system. Basically, directory locations on the hard drive to install SNAP are selected. If not already accepted earlier, license agreements are then displayed, which the user needs to agree to before proceeding. During the installation process, windows showing installation process and user-selectable installation options are displayed.

For SNAP/RADTRAD and AptPlot, a Java-based installer file named *snapinstaller.jar* is provided that guides the installation process of SNAP/RADTRAD. Screenshots of the windows for AptPlot and SNAP/RADTRAD produced by the installation process are presented in Figures 2-1 (AptPlot) and Figure 2-2 (SNAP/RADTRAD).

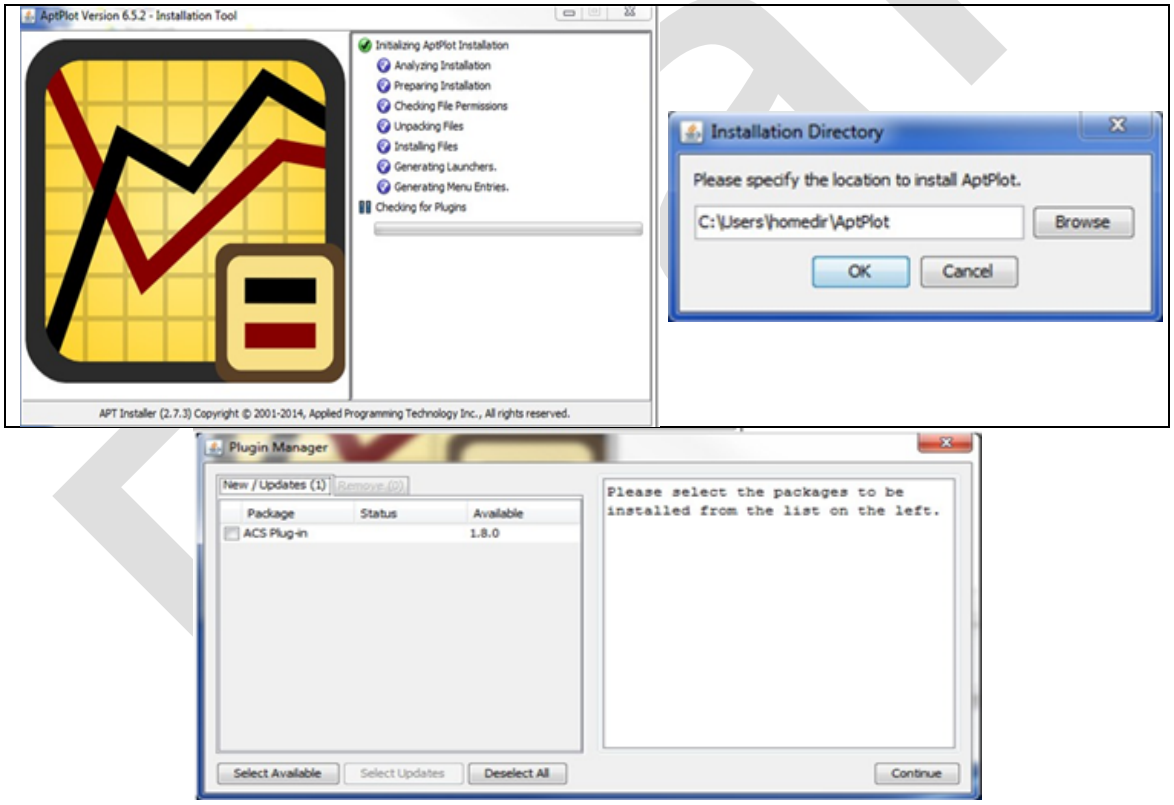

Figure 2-1 AptPlot installation screens

For AptPlot, the AptPlot Installation Tool, the user interface for AptPlot shows the progress of the installation. The location of the installation directory is shown in the *Installation Directory* window. The user can change the location although the default location is usually adequate.

After selecting the installation directory, the Java Runtime Environment License Agreement appears which the user must agree to in order for the installation process to proceed forward. Once this step is completed, a second license agreement for AptPlot (the GNU General Public license will appear which again the user must agree to in order to continue.

The user will then be required to select plugins. In the case of AptPlot, the user will select the analysis code support (ACS) Plug-in and then click on *Continue*. The installation will proceed to completion and the user clicks on *Close* in the *AptPlot Installation Tool* window to exit the AptPlot installation.

The installation steps for the SNAP/RADTRAD plugin are essentially the same as for AptPlot, although the windows are somewhat different. The SNAP Installation Tool is the user interface for SNAP installation which shows the progress of the installation. The location of the installation directory is shown in the *Installation Directory* window. The user can change the location although the default location is usually adequate. After selecting the installation directory, the Java Runtime Environment License Agreement appears which the user must agree to in order to continue the installation. Once this step is completed, a second license agreement for the APT binary code license agreement appears which again the user must agree to in order to continue.

The user will then be required to select plugins. In the case of SNAP, the user will select the *AVF*, *ENGTMPL*, *EXTDATA*, *RADTRAD*, and *Uncertainty* plug-ins and then click on *Continu*e. The installation will proceed to completion and the user clicks on *Close* in the *SNAP Installation Tool* window to exit the SNAP installation. If the user wants to know the purpose of each plug-in, the user can click on each package name and a description will appear on the right-hand side of the plug-in manager window as illustrated in Figure 2-2.

The installation files are written to the */users/homedir* where *homedir* is the home directory for the login ID being used unless you specified a different location. These files are included in the *snap* and *.snap* directories. The code files are written to the *snap* directory and files needed to use SNAP on a given system are written to *.snap*. For example, the location of the root folder on a given computer is written to the *.snap* directory. The installation files for AptPlot are also in */users/homedir* in the *AptPlot* and *.aptplot* directories. If the user is uncertain of the location of the home directory is, a *command* window can be opened by going to *Start* and typing in *command* in the Search textbox (Windows 7). A command prompt window should appear (select *Command Prompt* from menu above if necessary). Then, type in *echo %USERPROFILE%* and your home directory will be displayed.

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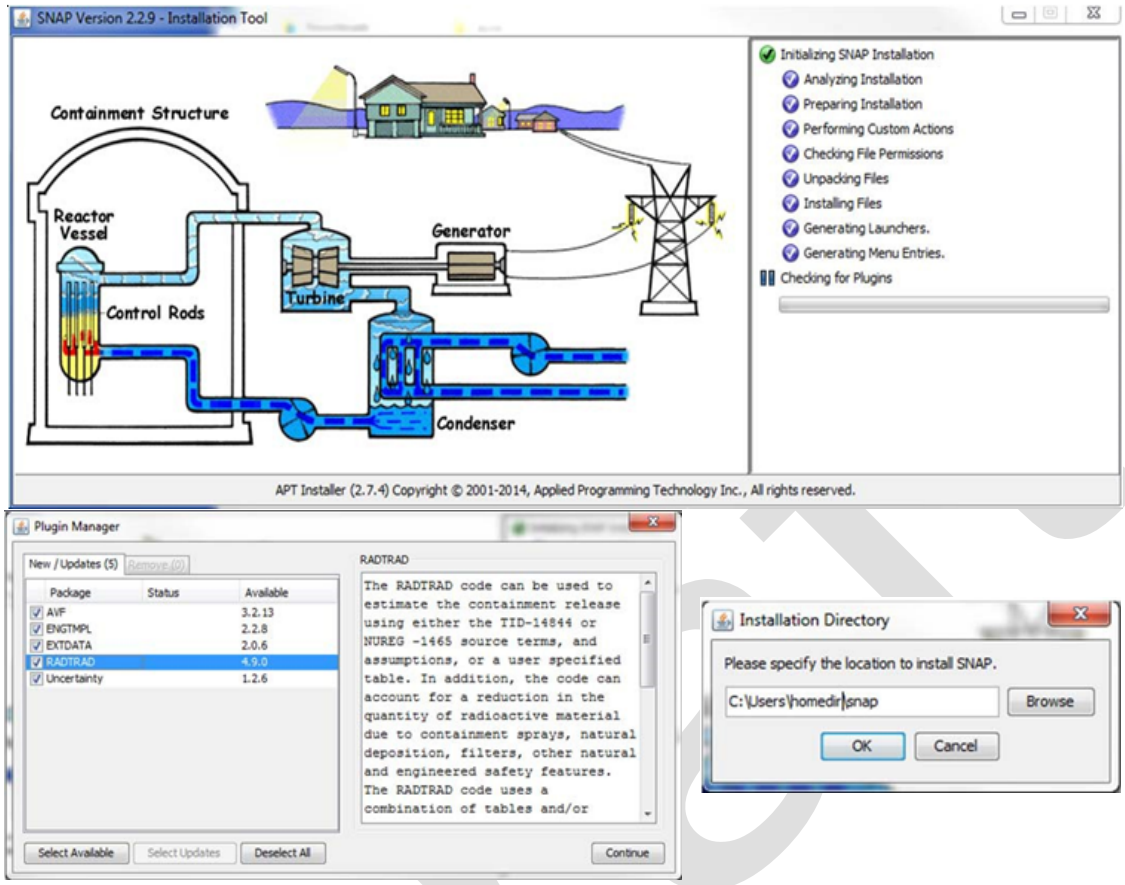

Figure 2-2 SNAP installation screens

Finally, the RADTRAD-AC should be installed in the *radtrad* subdirectory under the *snap* directory in the */users/homedir*. The RADTRAD-AC distribution consists of a group of Java *.jar* files that are distributed as a zip file from the RAMP website. These files are *castor-codegen.jar*, *castor-core.jar*, *castor-xml.jar*, *castor-xml-schema.jar*, *commons-logging.jar*, and *radtrad.jar*. To install these file, create a subdirectory named *radtrad* in the installation directory for SNAP/RADTRAD, unzip the files and copy them to that directory. The path to the *radtrad.jar* file needs to be set in the configuration tool. Note that the SNAP/RADTRAD installer automatically defines the path to the RADTRAD analytical code jar file as:

${SNAPINSTALL}/radtrad/radtrad.jar,

so if the aforementioned *.jar* files are copied to a *radtrad* subdirectory in the SNAP/RADTRAD installation directory, the code should be ready for use. The location of this link within the SNAP framework is discussed in Section 2.2.

2.4 Sample Problems

A set of sample problems for SNAP/RADTRAD are provided on the RAMP website. These problems provide a starting point for the user. In addition, there is a *Test23* sample problem provided with the SNAP installation files from APT. This problem is used to illustrate the use of SNAP/RADTRAD in Section 3.0. The user will also find the information on the *QuickStart.pdf* file on the RAMP website to be useful.

2.5 Contact Information

Any questions, suggestions, corrections or comments concerning this the code or its documentation should be submitted to RADTRAD_Help@nrc.gov or RAMP.Resource@nrc.gov.

2.6 Code Error and Problem Reporting

While every effort has been made to minimize errors in SNAP/RADTRAD, there may be unanticipated circumstances that lead to errors and problems (bugs). To report errors and bugs with the program, first collect as much information as possible about the error or bug. This information should include answers to the following questions:

- What version of the SNAP/RADTRAD program are you running? The information for SNAP can be found on the screen displayed at startup or by using the *Help* | *About* menu item. Click the *Plugins* button at the bottom of the popup screen to get the information about the SNAP/RADTRAD Plugin.
- What computer operating system is SNAP/RADTRAD being executed on?
- Is the error or bug reproducible?
- What are the steps leading up to the problem?
- What are the exact symptoms (e.g. program crash, error message, etc.)?
- Save the case files and attach them to an issue report.

To report a problem, send a zip file with the case files and answers to the above questions to RADTRAD_Help@nrc.gov.

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3.0 MODEL DEVELOPMENT USING SNAP/RADTRAD

To run SNAP/RADTRAD will require some familiarity with the overall SNAP approach to developing and running models. In this section, the approach to using SNAP to develop, modify and execute RADTRAD problems will be discussed. However, SNAP includes many features which will not be discussed here. However, for the interested user, the Symbolic Nuclear Analysis Package User's Manual [4] provides more detailed information on the use of SNAP.

3.1 Overview of SNAP/RADTRAD

SNAP is actually a suite of computer applications used to develop, modify, and execute computer models principally for thermal hydraulic codes such as the TRAC/RELAP Advanced Computational Engine (TRACE) and Reactor Excursion and Leak Analysis Program (RELAP5). Of these tools, the *Configuration Tool*, *Model Editor* and the *Job Status* tools are most relevant to RADTRAD analysis. The *Configuration Tool* is used to configure global properties for running RADTRAD under SNAP. The *Model Editor* provides a GUI used to develop RADTRAD models. The *Job Status* tool is used to obtain the job status. Of these tools, the *Model Editor* is the tool used the most as it is the primary tool for developing SNAP/RADTRAD models.

Generally, the approach for developing a new SNAP/RADTRAD model is to define the compartments and connections in flow pathways that represent the plant and optionally the control room and/or the technical support center being analyzed. Note that flow pathways are used to connect components in SNAP/RADTRAD. During the specification of components and flow pathways, removal models should be considered and specified for each normal compartment as appropriate. For compartments, these removal models include filtration, sprays, or natural deposition. The user will need to specify each model required and specify the required data using the SNAP GUI as a guide.

Once the geometric, flow/leakage and removal information is specified for the compartments and flow pathways, a source term is then specified. A comprehensive list of nuclides based on International Commission on Radiological Protection (ICRP) Report 38 [5] has been included in SNAP/RADTRAD. The user will need to decide whether the analysis is either being done based on the occurrence of a LOCA by selecting either TID-14844 or NUREG-1465 or for non-LOCA where both radionuclides from the fuel and the reactor coolant activity may be important contributors and make the appropriate selections for the plant being analyzed. A plant power level must be defined to obtain the correct source term. The iodine physical form must also be defined as the rate of removal and filtration depends on the physical form of iodine.

Parameters related to the dose rate are specified, including *X*/Q data for each receptor location and dose conversion factors (DCFs). Default DCFs based on EPA-520/1-88-020, “Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion,” Federal Guidance Report No. 11 (FGR 11) [6] and EPA-

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402-R-93-081, “External Exposure to Radionuclides in Air, Water, and Soil,” Federal Guidance Report No. 12 (FGR 12) [7] (see Section 4.6) are built into SNAP/RADTRAD. The EAB and the LPZ are defined by default in SNAP/RADTRAD. Other dose receptors can be added as needed. For each dose receptor that is located in the environment or draws from the environment such as a control room, time-dependent *X*/Q and breathing rate values must be specified. For the control room, occupancy factors must also be specified. Note that default values for breathing rates are provided that are suitable for most analyses.

SNAP/RADTRAD can be used to develop new models and modify existing models. The key aspect of model development is the use of compartments and connecting flow pathways to model a system. The approach used to prepare this section was to open the SNAP GUI and start exploring the features for RADTRAD model development. Therefore, the discussion in the following sections assumes that the user has SNAP available and open and that the user will follow along with the discussion by using the SNAP/RADTRAD Model Editor. There is no better way to learn how to use the SNAP GUI except to actually use it.

3.2 The Model Editor User Interface- Model Development

This subsection describes working within the SNAP/RADTRAD Model Editor to develop and modify models.

3.2.1 Overview of Existing Model Features

As noted earlier, the SNAP/RADTRAD Model Editor is the basic tool used to create, modify and run input models. To start the *Model Editor*, navigate to *Start->All Programs->SNAP->Model Editor*, and the *Model Editor* should start.

To illustrate many of the features in SNAP, the Test 23 sample problem will be used. This problem is found in the *Samples/Test23* subdirectory in the *snap* directory (see Section 2.3). It is recommended that a copy of the *Test23.med* file be placed in the user’s working directory, which is the directory where the input and output files will be kept. It is also recommended that the user open *Test23* and follow along with the presentation in this section.

When the *Model Editor* is started, a splash screen appears for several seconds and then a *Welcome to Model Editor* screen appears as shown in Figure 3-1 with the Model Editor window in the background.

Several options are available on the *Welcome to Model Editor* screen, which are listed below:

- *Create A New Model*
- *Open a Model Document*
- *Import a New Model*
- *Start an Empty Session*

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- *SNAP Version Updates*

Under each of these items a short description of each option is provided to explain what each option does.

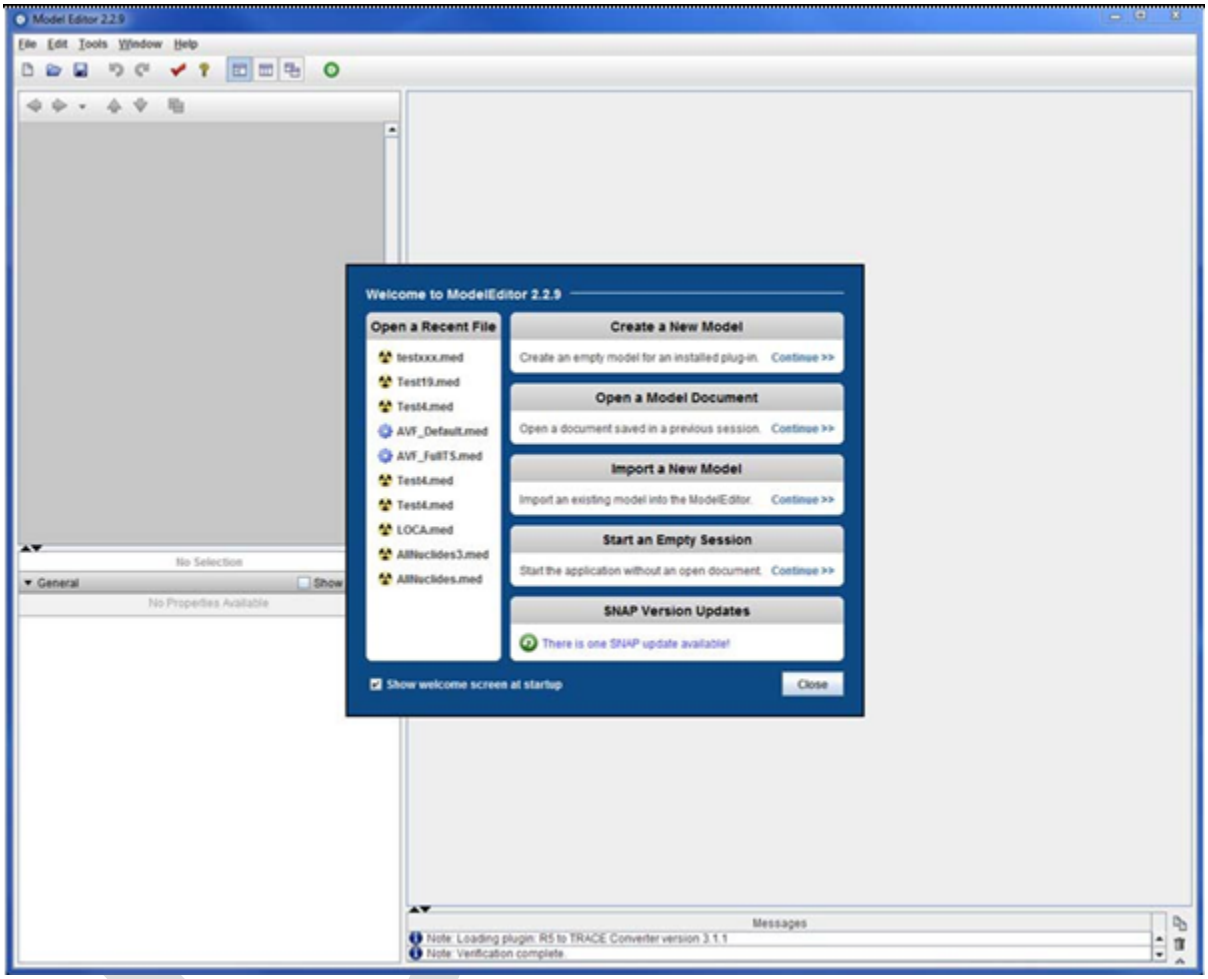

Figure 3-1 SNAP Model Editor welcome screen

Once the SNAP Model Editor is open, the user selects *Continue* under *Open a Model Document* on the Figure 3-1. Navigate to the location of the *Test23* subdirectory under the samples directory. Click on the file *Test23.med*. The Model Editor rendering of Test23 will open as shown in Figure 3-2. Alternately, the user can click on the *Test23.med* file in the working directory to start the SNAP Model Editor.

Finally, the model can also be opened by selecting *File->Open*, navigating to the input file (*.med* file) of interest, selecting that file and clicking on *open*, much like any Windows program. Notice that there are three separate input sections in the SNAP Model Editor window shown in Figure

3-2 which are: the *Navigator* window, the *Property* window and the *View / Dock* window where the model rendering appears. Also, notice that there are two tabs in the *View / Dock* window labeled *Default View* and *Test23 View*. In this model the SNAP/RADTRAD job stream is shown while the model rendering is shown in the Default View. The tabs can be clicked-on to show either the modeling rendering or the job stream (similar to Microsoft Excel). Job streams will be discussed later in this section. There is also a *Message* window underneath the *View / Dock* window which lists messages from SNAP/RADTRAD.

The user should note that each of the windows shown in Figure 3-2 can be resized either horizontally or vertically. Resizing is done by hovering the mouse cursor over the border between the windows until a double-headed arrow appears. Then the user clicks and drags the border to the desired location.

The user will need to unlock the model by clicking on the *Lock* ( ) icon shown in Figure 3-2. Notice that other icons adjacent to the *Lock* ( ) icon will change to unlocked ( ) on the toolbar.

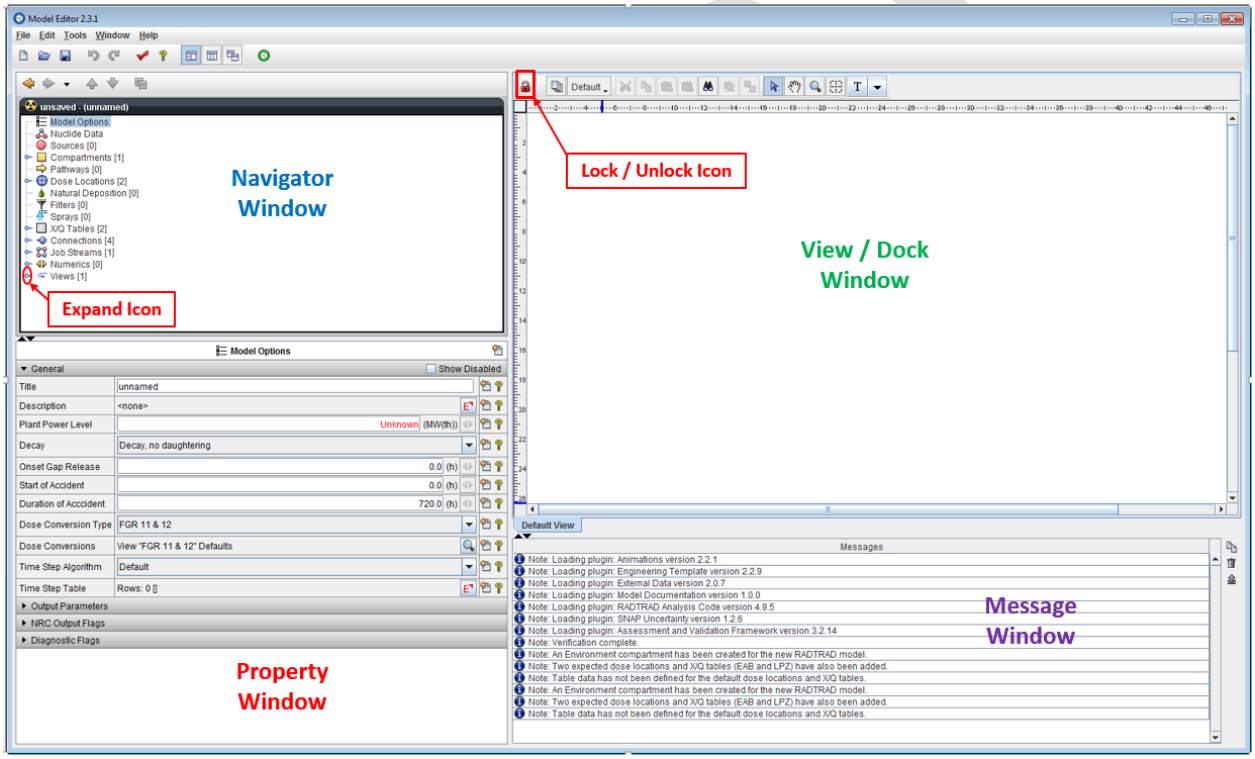

Figure 3-2 SNAP Model Editor screen

One powerful feature in SNAP/RADTRAD is the ability to check the model for input errors. To illustrate the use of this feature, click on *Tools->Check Model* to perform a model check. Note that the message *Note: Model check complete. No errors found* in the *Message* window at the bottom of the screen.

The input groups are shown in the *Navigator* window. Clicking on the *Expand* ( ) icon will expand each group and node, showing the associated input data for that input group and node. Figure 3-3 presents an illustration of a node expansion which is obtained by clicking on the *Expand* ( ) icon next to *Compartments*, then clicking on *Compartment 1*. Note that the Compartment 1 input appears in the *Property* window (lower left). The user should experiment with other input groups as the approach is the same. Input specification will be presented later in this section.

Note that the black bar where the input model name appears (*Test23.med*) contains some important features which are summarized in Section 3.4. One of these features is the ability to switch units from British to International System of Units (SI). Units switching is done by right-clicking on the black bar, selecting *Engineering Units->British* to change the units from SI to British.

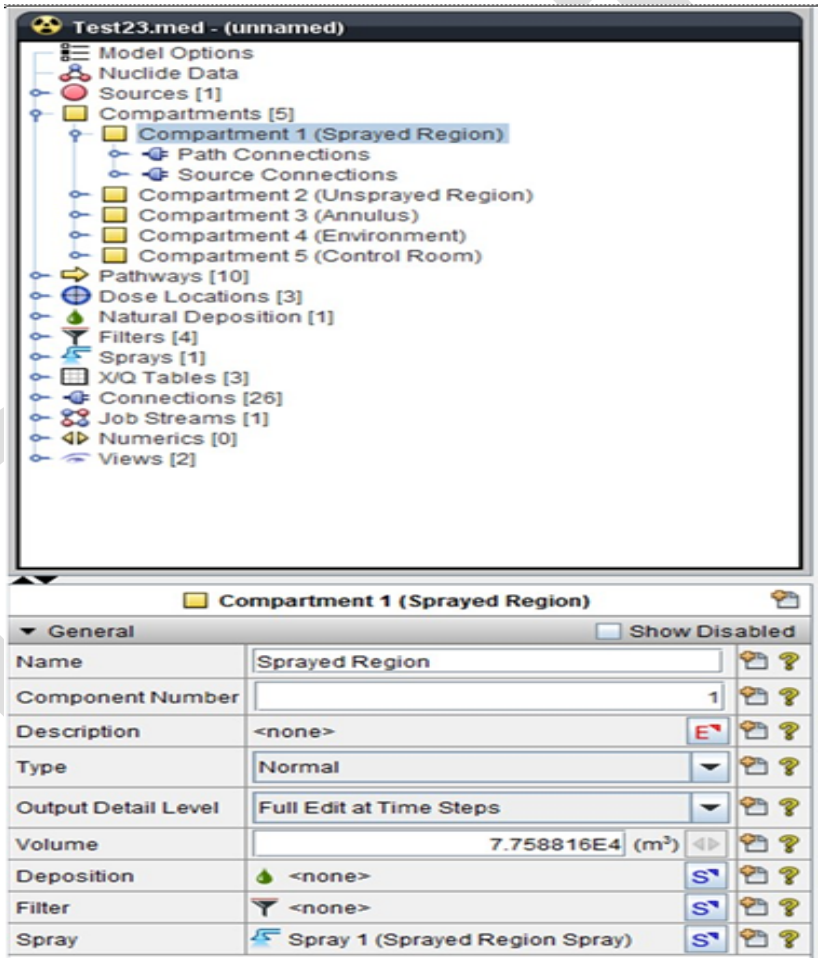

Figure 3-3 Illustration of the expand icon

Icons are used to represent the various components used in the *View / Dock* window that comprise a typical model. Figure 3-4 presents an illustration of the various icons used.

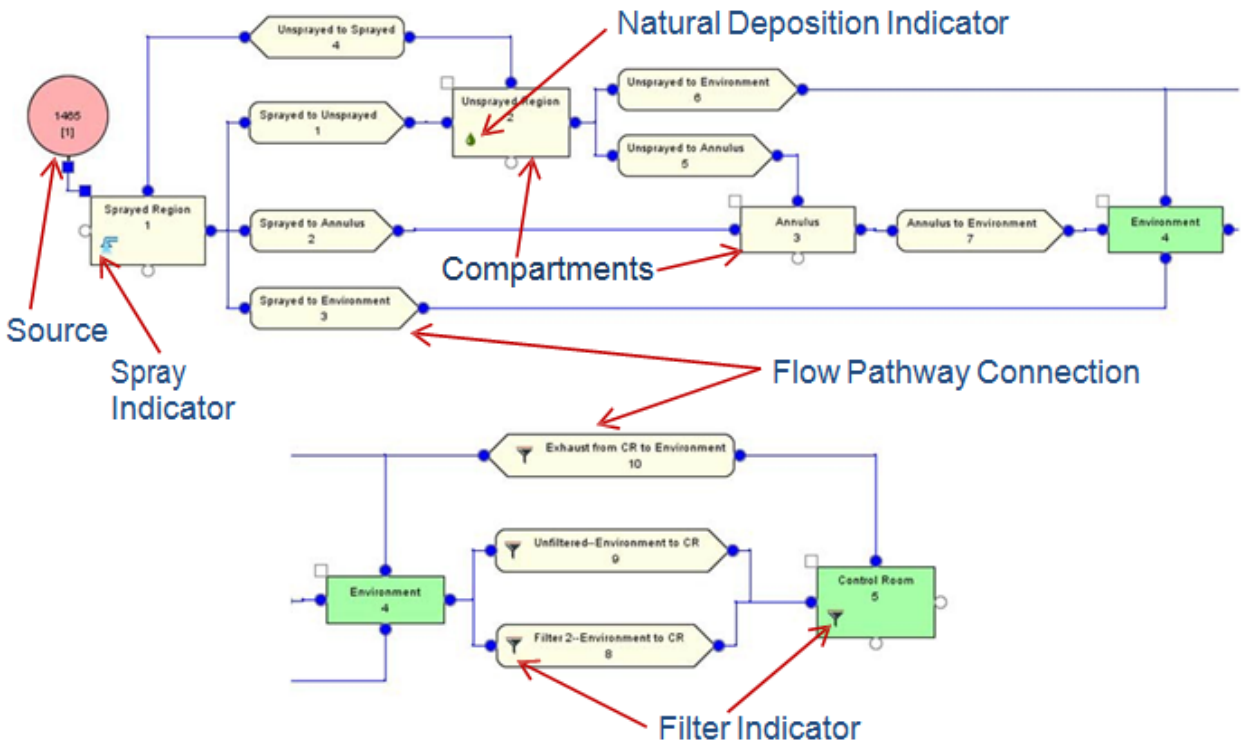

Figure 3-4 Illustration of the various icons used to represent a SNAP/RADTRAD model

3.2.2 Job Streams and Case Execution in SNAP/RADTRAD

Before continuing the discussion of existing model features and developing a new model, the Test23 case will be run to illustrate how cases are run.

Case execution is dependent on the job stream, which are a source of confusion for new SNAP/RADTRAD users. Simply put, job streams are used to pass input and output data from one code to another for cases where multiple codes are used. SNAP is used to support a wide variety of analysis programs that pass data from one program to another. This feature is less of an issue with SNAP/RADTRAD because in most cases, output from SNAP/RADTRAD (RADTRAD-AC) is passed to AptPlot for plotting. For the convenience of the user, a default job stream is predefined for all SNAP/RADTRAD cases.

Figure 3-5 presents a typical SNAP/RADTRAD job stream. The default job stream for SNAP/RADTRAD shows three steps: 1) input preparation shown in the *RADTRAD Model* (*Base_Model)* node, 2) the analytical code execution in the *RADTRAD* (*RADTRAD*) node and 3)

the passing of plot data from SNAP/RADTRAD to AptPlot (*PlotStep*) *node*. Input is passed from the Model Editor (*Base_Model*) to the RADTRAD analytical code (RADTRAD). The plot file data generated by the RADTRAD-AC is passed to the AptPlot (*PlotStep*) node.

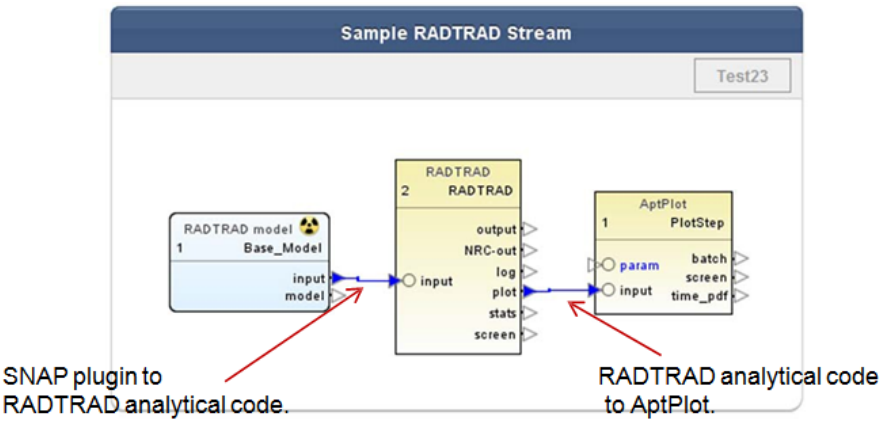

Figure 3-5 Typical job stream in SNAP/RADTRAD

As in the case of model input, job streams specification can also be checked. In the case of the Test23 problem, expand the *Job Stream* node in the *Navigator* window; select *Test23* and right-click, then select *Check Stream*. An error report window will appear in the *Message* window and in this case, no errors were found.

Part of the job stream input specification is to determine where the RADTRAD-AC output will be written. When the job stream node is expanded as above, the job stream properties appear in the *Property* window as illustrated in Figure 3-6.

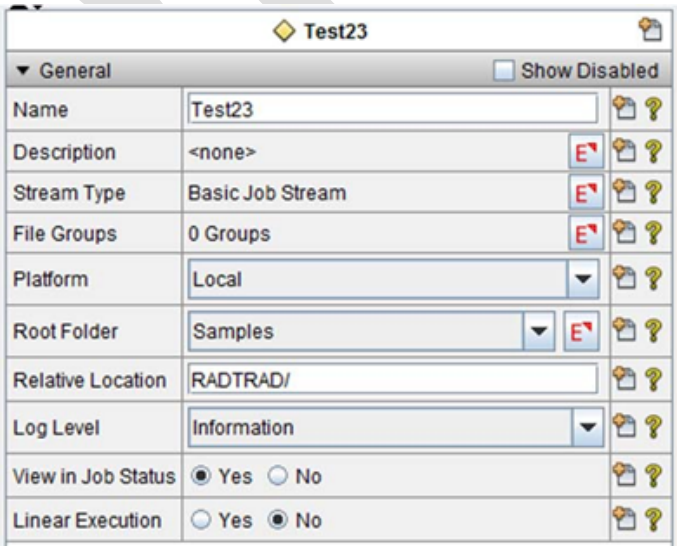

Figure 3-6 Job stream Property window

The two job stream properties which determine where the output is written are the *Root Folder* text box and the *Relative Location* text box. The SNAP/RADTRAD output is then the *Relative Folder* location appended to the *Root Folder* location. To review the root folder settings, click on the *Custom Editors* (E) icon and a window similar to that shown in Figure 3-7 appears. In this example, three root folders along with the path location are shown.

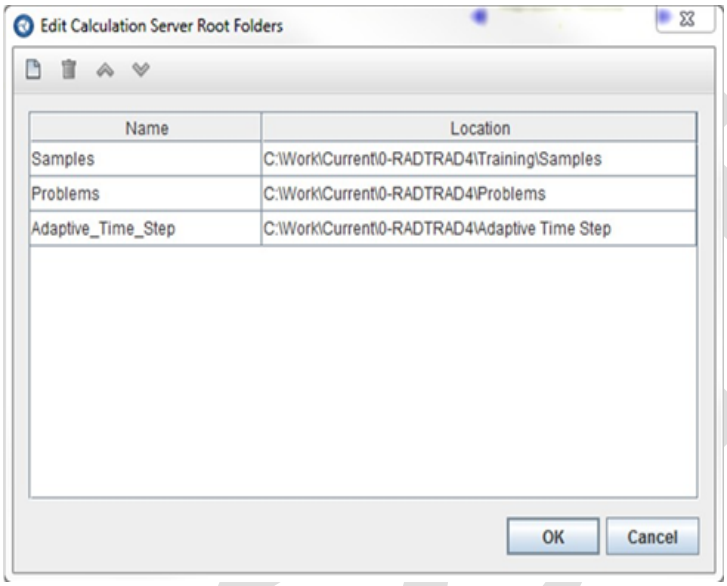

Figure 3-7 Typical root folder settings in SNAP/RADTRAD

Assuming that the root folder is set to *Samples*, the path to the output will be *Samples\RADTRAD* or *C:\Work\Current\0-RADTRAD\Training\Samples\RADTRAD*. In a new installation, the root folder is not set. When the root folder is not set, the message *No Root Folders Available* appears in red as shown in Figure 3-8.

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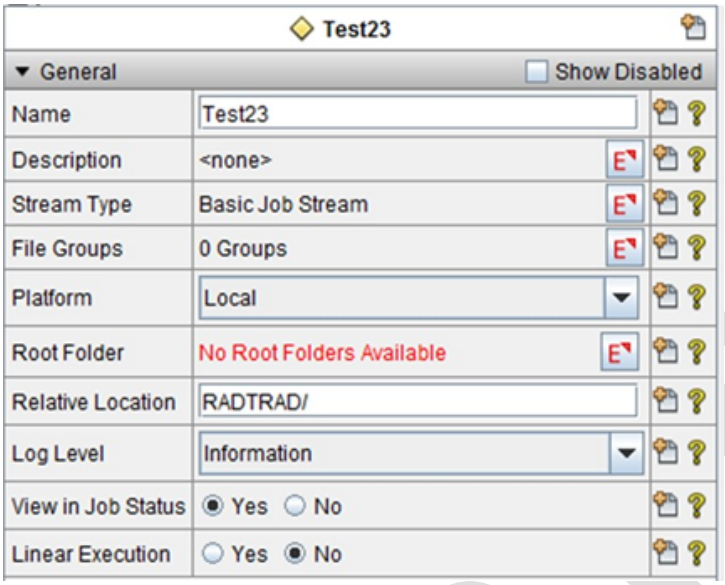

Figure 3-8 Job stream Property window with an unset root folder

Setting the root folder requires selecting the *Custom Editors* ( ) icon under the *Root Folder* text box to open the *Edit Calculation Server Root Folders* window. Click on the *New* ( ) icon and navigate to the desired location in the *Select Folder Location* window. The root folder name will change to the last folder name in the directory path.

The relative location can be reset and should be reset to a name more mnemonic so that the SNAP/RADTRAD cases can be tracked. For example, to change the name, highlight the Relative Location Name and type in a new name (*Sample to Test23*). Note that the file location is automatically appended.

Note that multiple root folders are allowed which is handy for organizing SNAP/RADTRAD case files. To add a root folder, navigate to *Tools->Job Status* or click on the *Job Status* ( ) icon and expand *Local*. Right-click on *Local* and select *Root Folders*. Click on the *New* ( ) icon (left on Toolbar) and navigate to where you want the root folder (ex. NPP Dose Analysis). The root folder path will be created. Also, a path of subdirectories can be specified in the *Relative Location* text box separated by a back slash (/). For example, the relative location can be set to *RADTRAD/LOCA,* so that the path to the output would be *Samples/RADTRAD/LOCA* assuming that the root folder is set to *Samples*.

A couple of points should be noted about root folders. First, the root folder directory needs to exist – otherwise you'll get a warning that the directory doesn't exist and the root folder will not be defined. Second, overlapping paths are not allowed and will generate an error. At this point, the user can run *Test23*. However, as a reminder, one item should be checked before proceeding and that is the link to the RADTRAD-AC. This link should have been set automatically during the installation process. The setting is:

${SNAPINSTALL}/radtrad.radtrad.jar,

assuming that the user placed the RADTRAD-AC code in a *radtrad* subdirectory in the SNAP installation directory in the user's home directory as discussed in Section 2.2. The setting can be checked by navigating to *Tools->Configuration Tool* and then expanding the *Applications* node by clicking on the *Expand* ( ) icon. Then, click on RADTRAD. Figure 3-9 shows the resulting window.

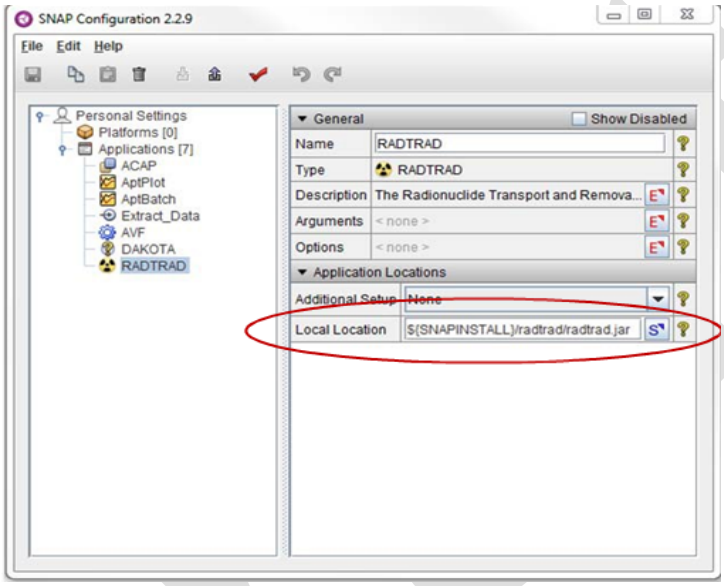

Figure 3-9 RADTRAD-AC code setting in the SNAP configuration tool

To run the Test23 or any other case, click on *Tools->Submit Job*. A *Submit Job Stream* window will appear as shown in Figure 3-10. Click on *OK* and a confirmatory *Submit Stream* window will appear. Finally, click *OK* and the run will start. The *SNAP Job Status* window will appear which is also shown in Figure 3-10. The *SNAP Job Status* window, in Figure 3-10 displays a completed job stream run.

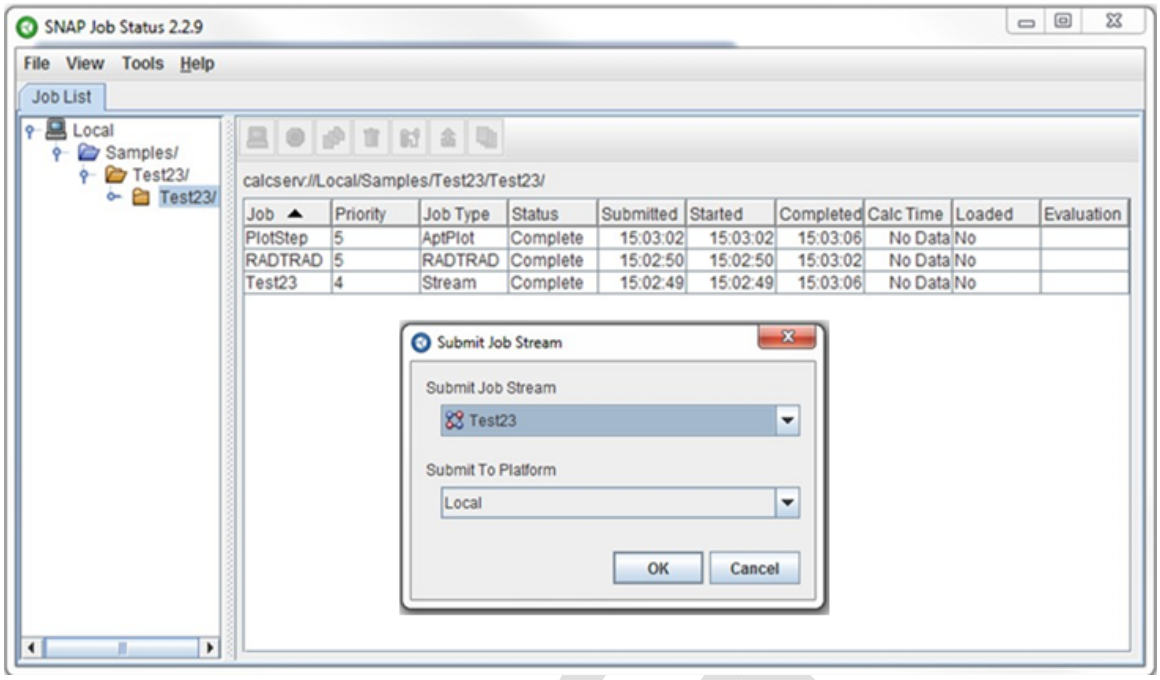

Figure 3-10 SNAP/RADTRAD job stream and status windows

The relationship between the SNAP/RADTRAD job stream and the actual case execution is shown in Figure 3-11. In the upper left-hand corner, the graphical job stream representation is shown. As noted earlier, this representation shows passing input from the SNAP GUI with the RADTRAD plugin to the RADTRAD-AC and then to AptPlot. The job stream properties are shown in the *Navigator* window shown in the upper-right corner of Figure 3-11. The links between the various nodes are also shown. In the *SNAP Job Status* window, the status of each of the job stream steps is shown. Again three steps are shown. The user interaction with the *SNAP Job Status* window will be discussed in Section 3.2.3.

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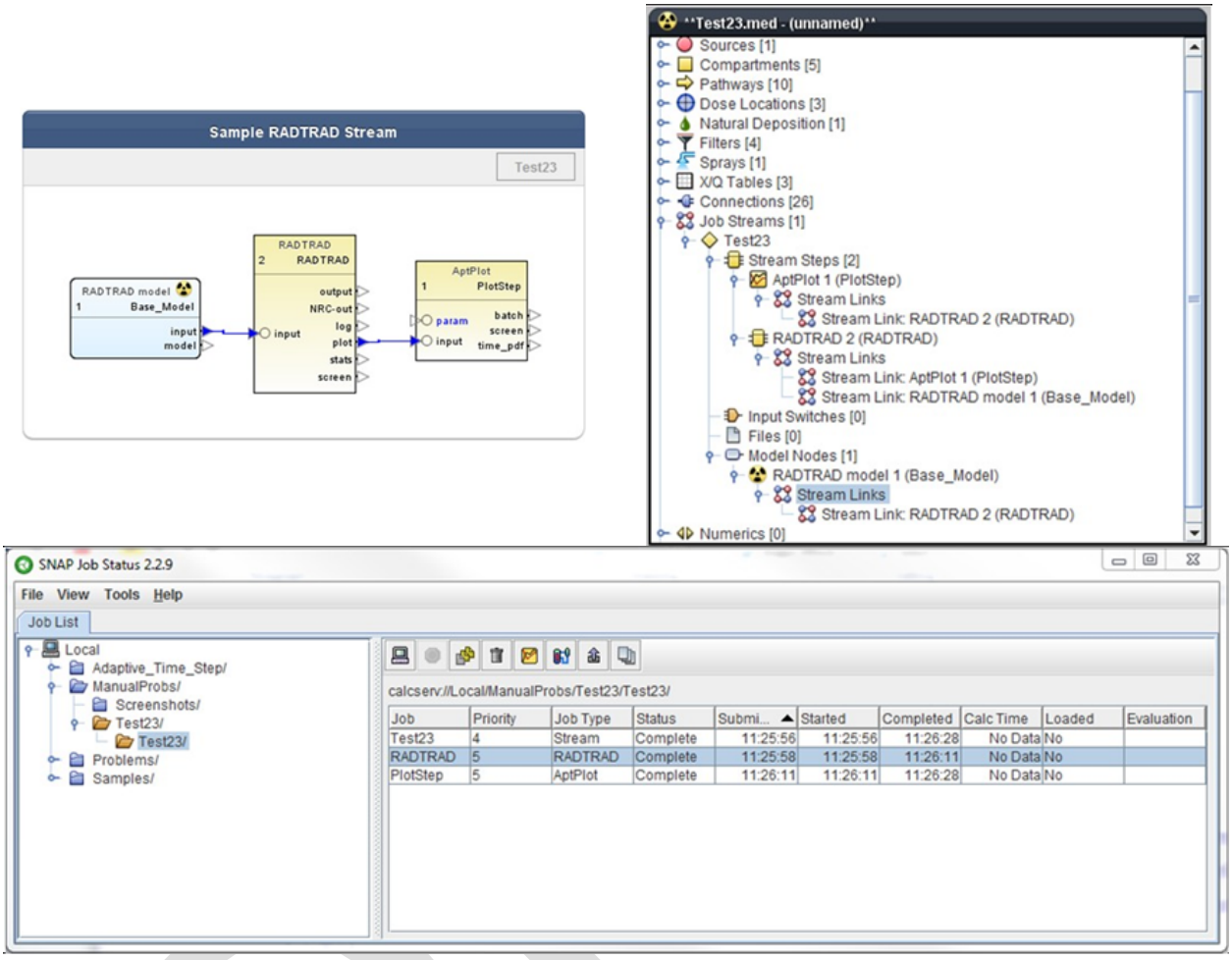

Figure 3-11 Relationship between job stream steps and code execution

Note that the *SNAP Job Status* window can be accessed from *Tools->Job Status* in the Model Editor for subsequent viewing. A summary of features relevant to SNAP/RADTAD available in the *SNAP Job Status* window are listed below:

- The *Job Console* ( ) icon – provides the time step history for the current job.
- The *Job Execution* ( ) icon – terminates the execution of the current job. This is only available when the job is running.
- The *Job Deletion* ( ) icon – removes the current job and files.
- The *AptPlot* ( ) icon – opens the selected job for plotting in AptPlot.
- The *File Viewer* ( ) icon – starts the output file viewer.

3.2.3 SNAP/RADTRAD Input and Output Files

There are a number of files produced that the user should be aware of in SNAP/RADTRAD. The main SNAP/RADTRAD interface file is the *casename.med* file where *casename* is the name of the case being analyzed. The *casename.med* file contains the data needed to render the model in the SNAP GUI, the default data used by the code and the user-specified input data. Section 3.4 discusses the actual input that can be specified for a SNAP/RADTRAD model.

When a SNAP/RADTRAD case is executed through the RADTRAD-AC, the data flow is not directly from the *casename.med* file. Rather, there are a number of data files that are produced by the SNAP/RADTRAD plugin that are read by RADTRAD-AC. These files, which are in extensible markup language (XML) format, include DCFs (*.dfx*), nuclide data (*.nix*), plant information (*.psx*), release fraction (*.srx*), and nuclide inventory (*.icx*) files. Output files (*.out*, *.screen* and *.plot*) are produced by the RADTRAD-AC. Log files produced by SNAP/RADTRAD are job stream related files (*.streamlog* and *.taslog*). Table 3-1 provides a brief description of these files.

When case execution is completed, the SNAP/RADTRAD output can be reviewed by clicking on the *File Viewer* ( ) icon. Note that there is a context in terms of the active job stream step and the output that is displayed. If the *casename* step is highlighted, then the job stream log will be available for viewing. If the *RADTRAD* step is highlighted as shown in the *SNAP Job Status* window in Figure 3-12, then the RADTRAD-AC output is available. If the *PlotStep* is highlighted, then the plot file data can be viewed using AptPlot. Figure 3-12 shows a screenshot of the dropdown menu cascade from the *File Viewer* ( ) icon for the *RADTRAD* job step from the *SNAP Job Status* window.

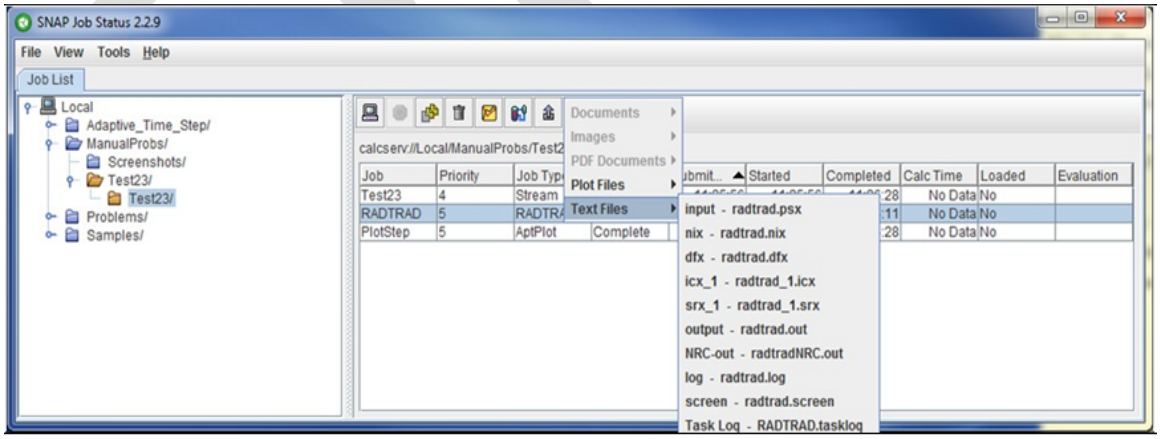

Figure 3-12 Dropdown menus for SNAP/RADTRAD output

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Table 3-1 Files available for viewing using the file viewer in the job status window

File Name	Description
Job Status Window *Casename* Files	
StreamLog - *Casename.streamlog* [a]	Output from job stream manager. Provides a high-level summary of the execution steps for the job stream. Typically not reviewed by the SNAP/RADTRAD user.
Job Status Window *RADTRAD* Files	
Plot Files - > plot - *radtrad.plot* [c]	Data file for AptPlot from the RADTRAD-AC.
Text Files - > input – *radtrad.psx* [b]	Plant data input file in XML format. Includes the plant-specific data specified by the user including model parameters, information for plant geometry for each compartment, information for each flow path, dose point information including X/Q and breathing rates, occupancy factors, and information for various radionuclide removal models (sprays, natural deposition, and filters).
Text Files - > nix – *radtrad.nix* [b]	Nuclide data information from ICRP-38 in XML format. Includes the atomic mass, half-life (s), and branching ratios for radionuclide daughters.
Text Files - > dfx – *radtrad.dfx* [b]	DCF file in XML format based on FGR 11 and 12 (see Section 4.6). Includes the organ-specific DCFs. Note that only the cloudshine (immersion) and the inhaled chronic [total effective dose equivalent (TEDE)] and skin DCFs are used to determine dose. Organ-specific factors as well as those factors for groundshine, inhaled acute and ingestion are not used.
Text Files - > *icx_1* – *radtrad_1.icx* [b] Text Files - > *icx_2* – *radtrad_2.icx* [b] (etc.)	Initial radionuclide inventory file in XML format.
Text Files - > *srx_1* – *radtrad_1.srx* [b] Text Files - > *srx_2* – *radtrad_2.srx* [b] (etc.)	Release fraction information file for each radionuclide group.
Text Files - > *output* – *radtrad.out* [c]	Output file from the RADTRAD-AC in the original format.
Text Files - > NRC-out – radtradNRC.out [c]	Output file from the RADTRAD-AC in the revised NRC format.
Text Files - > log – radtrad.log [a]	Debug output (usually not referred to by the user).

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File Name	Description
Text Files -> screen – radtrad.screen [c]	Problem time output to show progress of a given case.
Text Files -> Task Log – RADTRAD_tasklog [a]	Output from SNAP job steam showing RADTRAD job step execution information (usually not referred to by the user).
Job Status Window *PlotStep* Files	
PDF Documents – time_pdf – time.pdf [c]	Time step results (usually not referred to by the user).
Text-Files -> screen – aptplot.screen	Screen output from AptPlot (usually not referred to by the user).
Text-Files -> Task Log – PlotStep.tasklog	Output from SNAP job steam showing AptPlot job step execution information (usually not referred to by the user).

a. SNAP/RADTRAD specific output.
b. Input file to the RADTRAD-AC analytical code generated by SNAP/RADTRAD plugin.
c. Output file from the RADTRAD-AC analytical code.

The files produced by the RADTRAD-AC code which are *radtrad.out*, *radtradNRC.out*, *radtrad.plt*, and *radtrad.screen* are the most relevant to the user. The *radtrad.out* file is basically the original (Version 3.03/3.10) output file. Major sections of this output file are:

- Input listing – provides a listing of the input in XML format that is used by the RADTRAD-AC.
- Input echo – provides an edited input summary of plant description (model), scenario (radionuclide source term/DCF) information, compartment/pathway data, X/Q, DCF and decay data, and other relevant input.
- Breakdown of dose results and nuclide inventory in various compartments at various time points generally selected by changes in events (i.e. time at which flow rate changes, and time at which X/Q changes). Activity balance information is also given.
- I-131 inventory in various compartments as a function of time.
- Cumulative dose results at various dose locations as a function of time.
- Worst two-hour doses at the EAB and the final doses and final doses for the LPZ and other dose locations.

The output contents can be controlled from *Model Options* node by expanding the *Output Parameters* tab in the *Property* window (Figure 3-130. The main difference in the output is

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generally the editing of results for supplemental time steps when they are used and the model removal/decontamination factors.

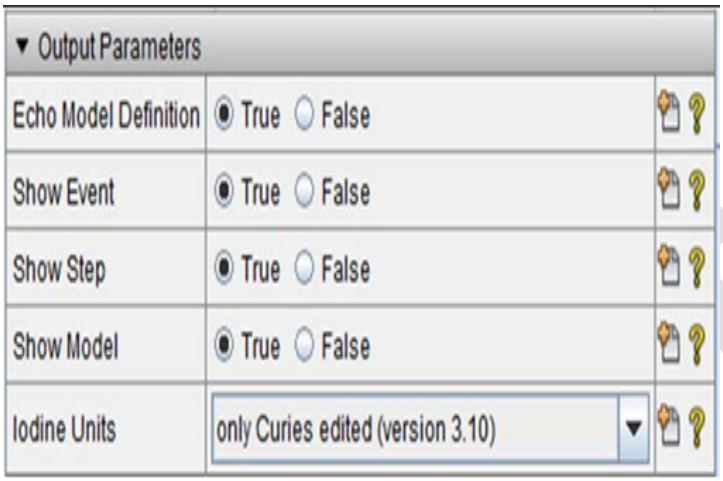

Figure 3-13 Expanded Output Parameters tab in the Property window

The *radtradNRC.out* output file provides a time-dependent summary of activity and dose calculations by nuclide. The contents of the *radtradNRC.out* file are controlled by expanding the *NRC Output Flags* tab under *Model Options* node in the *Property* window. See Figure 3-14 for the output parameters available. Major sections of this output are:

- Input echo – provides an edited input summary of plant description (model), scenario (radionuclide source term/DCF) information, compartment/pathway data, X/Q, DCF and decay data, and other relevant input.
- Output – activity distribution, cumulative and dose difference (delta-dose) for each dose component (inhalation, cloudshine, skin, thyroid, and TEDE).
- I-131 inventory in various compartments as a function of time.
- Cumulative dose results at various dose locations as a function of time.
- Worst two-hour doses at the EAB and the final doses and final doses for the LPZ and other dose locations.

The *radtrad.screen* file lists the time step history for a given SNAP/RADTRAD case.

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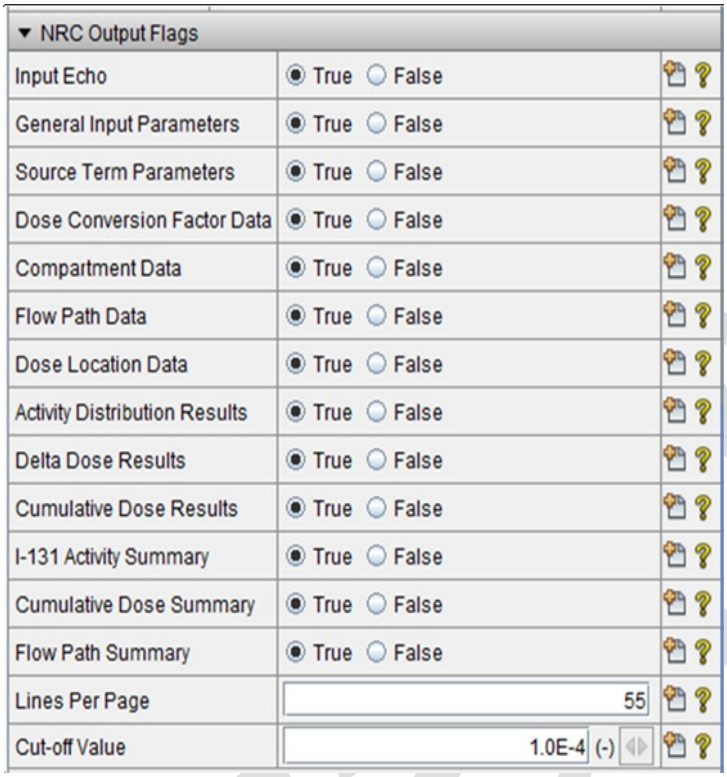

Figure 3-14 Expanded NRC Output Flags tab in the Property window

3.2.4 AptPlot Plotting Program

A feature of SNAP/RADTRAD is the ability to display plots of dose results. To display a plot, click on *Plot Files* and select *plot – radtrad.plt*. AptPlot will open. Alternately, click on the *AptPlot* ( ) icon in the *SNAP Job Status* window and AptPlot will open as illustrated in Figure 3-15.

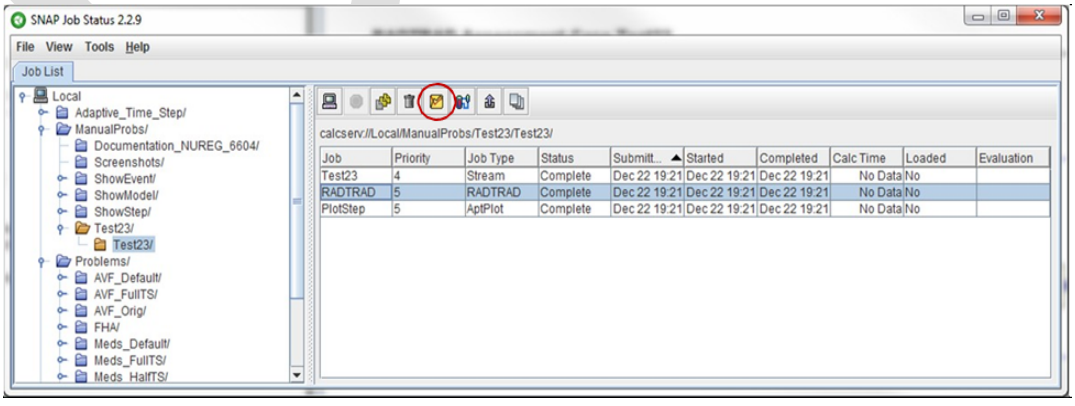

Figure 3-15 SNAP/RADTRAD Job Status window with AptPlot icon highlighted

When AptPlot opens, the windows presented in Figure 3-16 will appear. Dose information by dose location (*ExclusionAreaBoundary*, *LowPopulationZone*, and *ControlRoom* spaces omitted) and dose category (*body*, *cloudshine*, *skin*, *tede*, and *thyroid*) for each nuclide separated by periods will be presented in the *Select EXTDATA Channels* window in Figure 3-17. In AptPlot, each data set is referred to as a data channel. Test Problem 23 is used to illustrate the features of AptPlot and it is suggested that the user open AptPlot for Test Problem 23 and follow the discussion below.

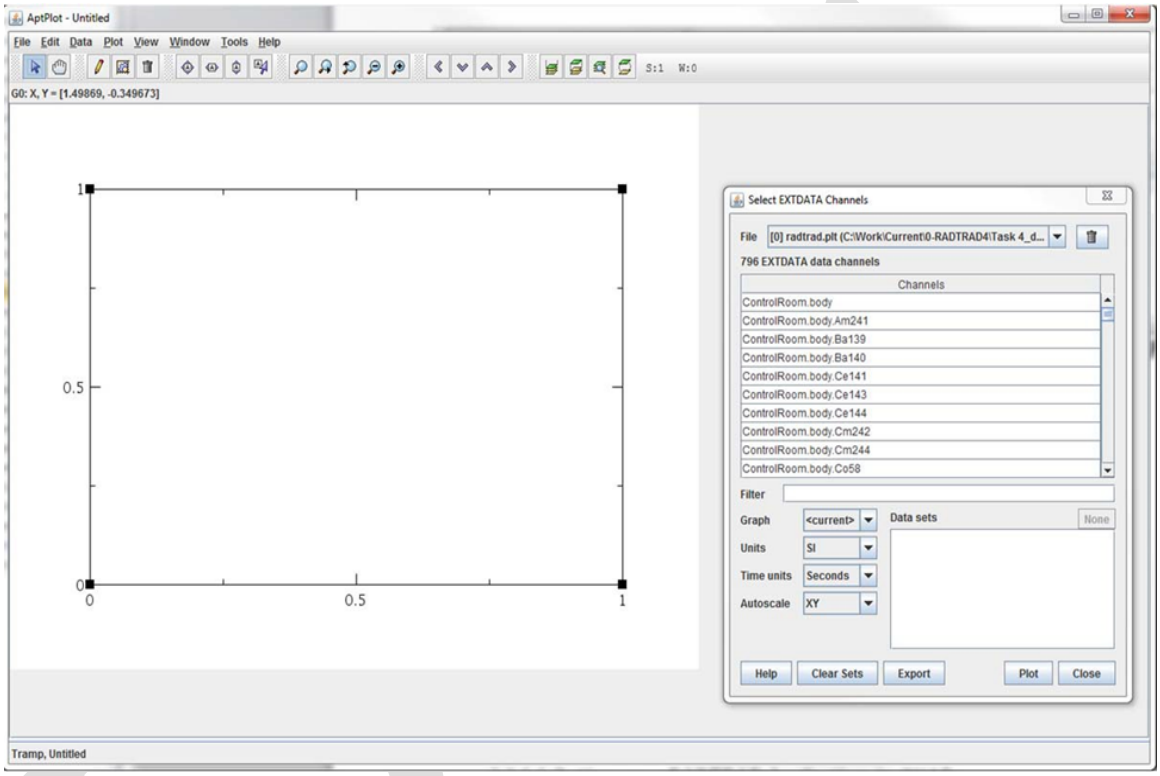

Figure 3-16 AptPlot startup view

Basically to make a plot, the user scrolls to the result of interest, highlights that result, clicks on the *Plot* button and the plot will appear. Note that the default time units are in seconds, but that can be changed to hours in the dropdown menu next to *Time Units* text box on the *Select EXTDATA Channels* window (Figure 3-17) prior to actually generating the plot.

AptPlot has many features for generating and formatting plots and the discussion presented here is not meant to be exhaustive. A comprehensive help manual can be obtained by selecting *Help->Help Contents* from the top menu. However, some of the more commonly used features are illustrated here.

As the user gains familiarity with the naming convention, the filter feature can be used to locate specific results of interest by entering the dose location, dose category, and nuclide of interest in

the *Filter* text box. If the user wants to plot the TEDE dose results for the control room, enter the text string *ControlRoom.tede** in the *Filter* text box. Note that the total TEDE dose ends with *tede* (i.e. no nuclide is listed). Also note that the asterisks (wildcard) symbol is used to control the list of all items. Wildcards can be embedded in the string (i.e. *ControlRoom.*.I**) to list the control room dose categories for all iodine nuclides. It is very important to note that the case of a character counts in applying filters in AptPlot, otherwise the wildcard search feature will not work properly. The spelling of the dataset name in the data channel window provides a guide for spelling a channel name.

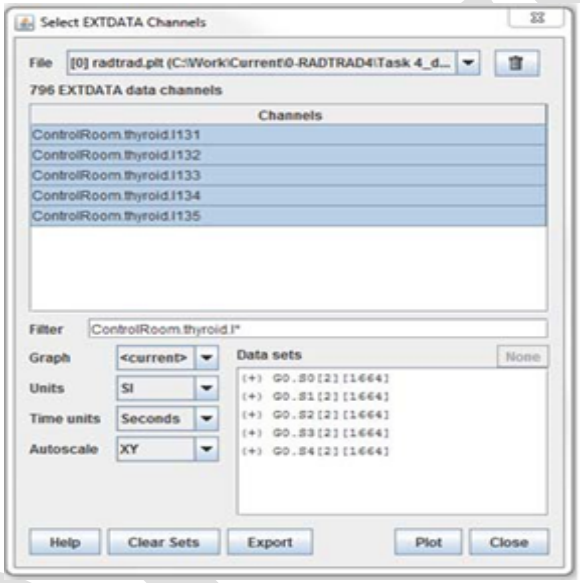

Figure 3-17 Select EXTDATA Channels window for multiple plots

Multiple data results can be plotted by highlighting the data of interest and clicking the *Plot* button. As an example, suppose the user wants to plot the thyroid dose for I-131 through I-135 for Test Problem 23. The user would enter *ControlRoom.thyroid.I** in the *Filter* text box, then select the resulting data channels in the *Select EXTDATA Channels* window and click on the *Plot* button to make the plot. This string can be shortened to *C*R*th*I** as a further example of the application of wildcards. To select multiple data channels requires the use of shift-click or control-click feature as described below:

- *Shift-click* – used to select a range of datasets. In this case, click on *ControlRoom.thyroid.I131*. Then hold down the shift key and select *ControlRoom.thyroid.I135*.

- *Control-click* – used to select multiple datasets one at a time. Hold down the control key and click on each dataset, selecting that dataset. Each dataset is highlighted after selection.

With either approach, all of the dose datasets will be highlighted as shown in Figure 3-17. Once the datasets are highlighted, click on the *Plot* button and the plot will be generated. The resulting plot is shown on Figure 3-18.

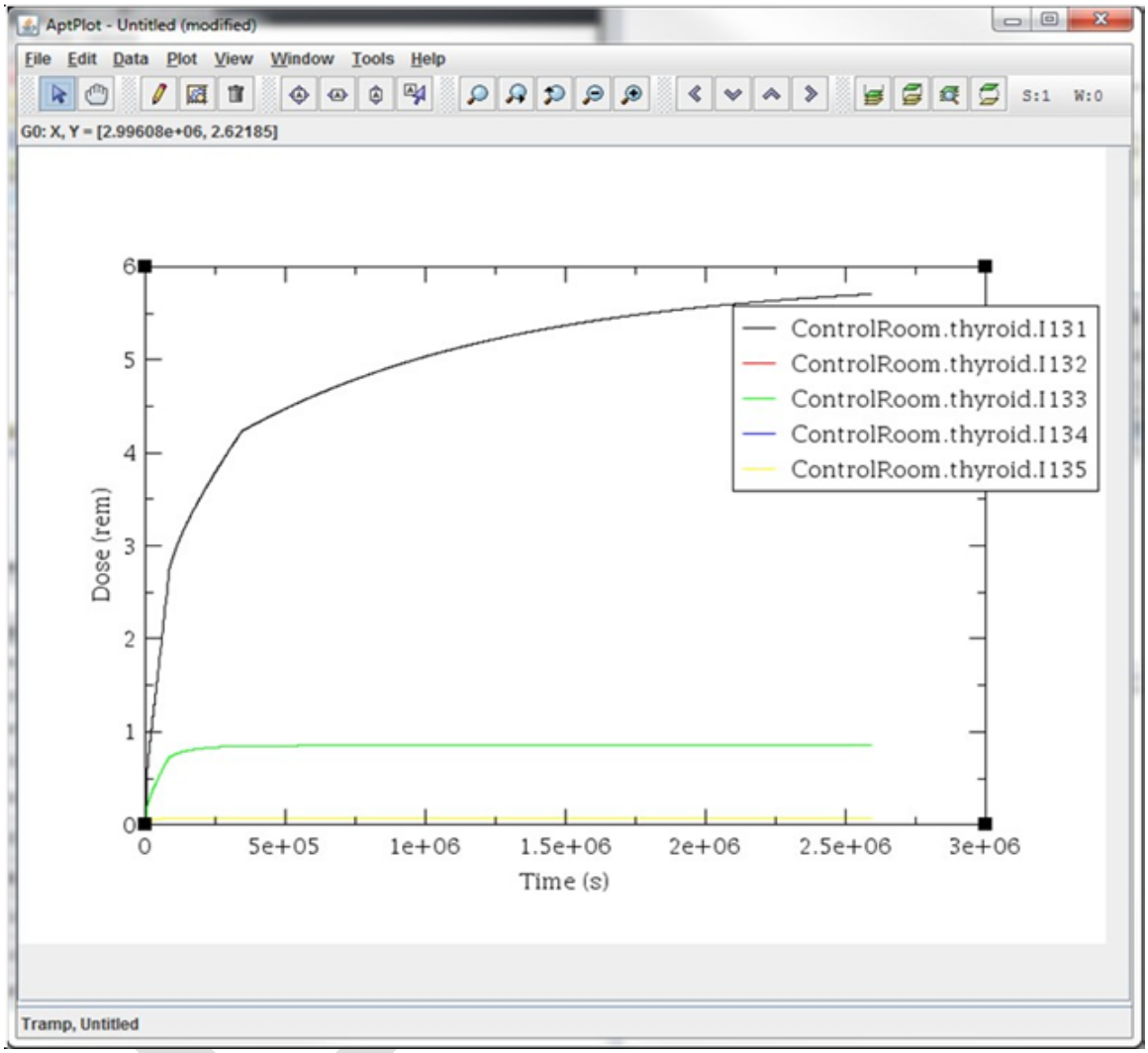

Figure 3-18 Control room dose plots for Test23

Adjustments can be made to the plot by using the plot editing features in AptPlot. These features are accessed by selecting *Plot* in the top menu. A number of features are available, but generally *Plot->Graph appearance*, *Plot->Set appearance* and *Plot->Axis properties* provide the features needed to edit the plot. Screenshots of each of these windows are shown in Figures 3-19 through 3-21. Clicking on the tabs in each window shows various properties and features available to the user. A subset of these features is used to edit the plot.

Some typical AptPlot adjustments are illustrated below:

- Change the x-axis scale from seconds to hours: − Navigate to the *Select EXTDATA Channel* window shown in Figure 3-17 and click on *Clear Sets* in the lower left-hand portion of the screen. Then change the units in the *Time Units* dropdown menu from *Seconds* to *Hours*. Confirm that the dose components are highlighted as shown in Figure 3-17 using *shift-click* or *control-click*. Then, click on *Plot* and *Time (hours)* will appear on the x-axis.

- Reset y-axis to logarithmic scale: − Given that the I-131 dose is so dominant, it is hard to read the dose contributions from the other iodine nuclides. The y-axis scale can be changed to logarithmic by navigating to *Plot->Axis properties*. Change the axis setting in *Edit* text box from *X axis* to *Y axis* and click on the *Main* tab if it is not already selected in the *Axes* window (Figure 3-19). Then change the *Scale* text box from *Normal* to *Logarithmic* and click the *Apply* button to change the y-axis to logarithmic.

- Expand y-axis to cover dose range: − The dose range can be expanded from the *Axes* window by changing the Start and Stop values to 0.0001 and 10.0. Click on the *Main* tab if it is not already selected. Then, enter *0.0001* in the *Start* text box and *10.0* in the *Stop* text box. Then click the *Apply* button to apply the change.

- Use scientific notation for the y-axis: − The format for the y-axis labels is set by changing the *Edit* dropdown menu setting in the *General* section of Figure 3-19. Then, set the number format in the *Format* dropdown menu in the *Tick properties* section to *Scientific* from *General*. Also set the precision to *0* in the *Precisio*n dropdown menu and click the *Apply* button to reset the format.

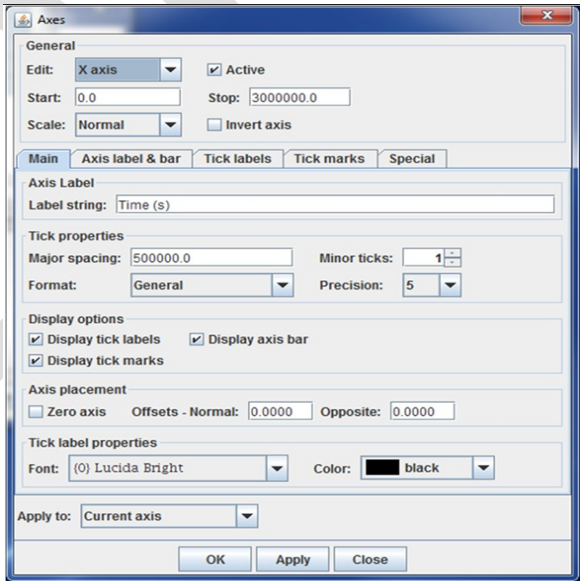

Figure 3-19 AptPlot Axes window

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- Line colors: − The line colors selected by AptPlot can be hard to see. Each line color can be individually adjusted by the user. To adjust a line color, navigate to *Plot - >Set appearance* and highlight the dataset to be changed in the *Data sets* section near the top of the *Set appearance* window (Figure 3-20). Note that the name of the data contained in a given dataset is identified by the *String* text box in the *Legend* section in the lower part of the window. Also, note that the current color of a particular dataset is shown in the *Color* dropdown menu in the *Line Properties* section. Using that dropdown menu, select the desired color and click on the *Apply* button. Alternately, to change the color of all lines to black for example, highlight all datasets using *shift-click* or *control-click* or alternately clicking on the *All* button. Then, select *Black* in the *Color* dropdown menu (if it is not already selected) and click on the *Apply* button.

- Line symbols: − Symbols for the lines are set from the *Main* tab in the *Set appearance* window. To select a symbol for a particular data set, highlight the dataset in the *Data sets* section, then select a symbol type (circle, square, etc.) under the *Type* dropdown menu in the *Symbol Properties* section. Also, select the desired color in the *Color* dropdown menu and click the *Apply* button. A symbol will appear for each data point and since there are hundreds of data points, a symbol skip will have to be set. Select the *Symbols* tab in the *Set appearance* window and highlight the dataset to be changed. Then, set the *Symbol* skip to a value like *50* or *75* and click on the *Apply* button. This setting will display a symbol for every 50th or 75th point, then repeat these steps for each dataset.

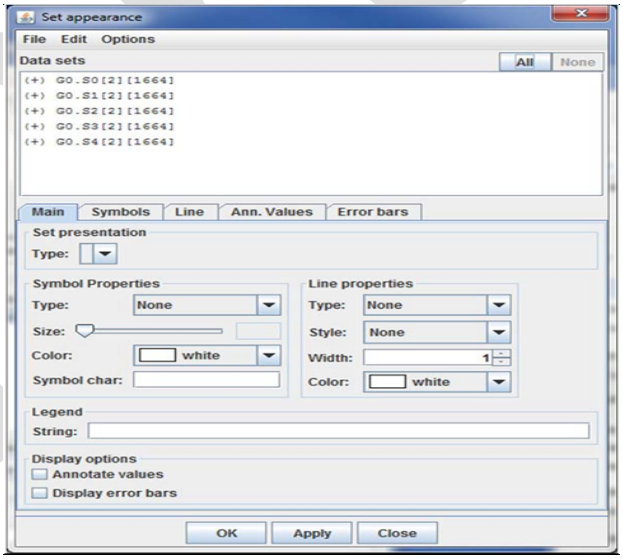

Figure 3-20 AptPlot Set appearance window

- Line style: − Line styles (solid, dash, dot-dash, etc.) can be set by selecting the *Main* tab in the *Set appearance* window, highlighting the desired data set in the *Data sets* sections

and selecting the desired style using the *Style* dropdown menu in the *Line Properties* section in a manner similar to setting line colors and line symbols. Each line is set individually, then click the *Apply* button as the settings for each dataset are completed.

- Titles and subtitles: − To add a title and subtitle to the plot, select the *Main* tab in the *Graph appearance* window (Figure 3-21). Enter a title and subtitle as appropriate, then click on the *Apply* button. The title and subtitle will appear. Select the *Titles* tab and use the sliders to adjust the font size for the title and subtitle as desired. Note the font size can be incremented by clicking on the channel to the left or right of the slider icon.

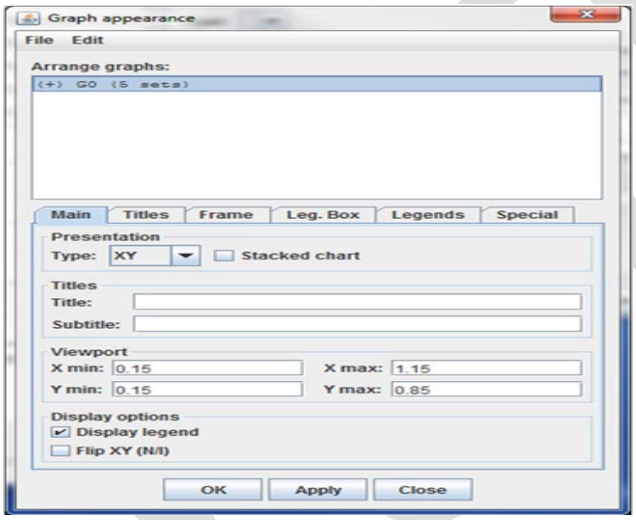

Figure 3-21 AptPlot Graph appearance window

Sometimes the legend box overwrites the dose results as in the plot shown in Figure 3-16. In order to correct this issue, the plot needs to be shrunk, which will require using several AptPlot features. These features are listed below:

- Edit the legend titles: − The title for each legend can be edited. This change is made by going to the *Set appearance* window (Figure 3-20) and highlighting the desired data set. Change the title in the *String* text box in the Legend section as appropriate. In this case, the iodine nuclide name is used. Click on the *Apply* button after each title modification is made.

- Change the font size for the legend: − First, the font size used in legend box will need to be reduced, which entails changing the legend title font and the symbol font. To change the font size of the legend title, navigate to the *Graph appearance* window (Figure 3-21) and select the *Legends* tab. Then, use the slider bar to adjust the font size to *75* for example and click on *Apply* button. The font size will change for all datasets. For the symbol size, navigate to the *Set appearance* window (Figure 3-20) and select all

datasets. Then, change the *Size* setting in the *Symbol Properties* section to *75* using the slider.

- Change the size of the plot: − The plot overlays a white background which is basically set to allow a plot to be printed on 8.5 x 11 paper in landscape mode. So, it is desirable to maintain this setting although it can be changed by navigating to *View->Page* setup. However, the approach used here is to shrink the plot by adjusting the settings in the *Viewport* section in the *Graph appearance* window (Figure 3-21) by entering suitable values. In this case, the *X max* and *Y max* text box settings are changed to 1.0 and 0.8, respectively. These settings permit the legend box to be moved to the right-hand side of the plot, then click on the *Apply* button. Then, to move the legend box, select the *Leg. Box* tab in the *Graph appearance* window (Figure 3-21) and adjust the box location in the *X* and *Y* text boxes in the *Location* section. Values of *1.05* and *0.60* will move the legend box to the right-hand side of the plot. Another approach is to change the *X max* text box setting to *1000* which will allow sufficient space for the legend box within the plot frame, although it will probably need to be moved for aesthetic reasons.

The plot is saved by navigating to *File->Save*, navigating to the desired directory location, entering a suitable name, then click on *OK*, similar to any Windows program. To access a previously saved AptPlot plot, navigate to *File->Open*, and navigate to the directory location where the plot file is saved and select that file. Also, the format and title settings can be saved by navigating to *Plot->Save defaults* and overwriting the *Defaults.agr* file. Note that *Plot->Reset defaults* will reset the defaults to the original settings. Figure 3-22 shows the resulting plot with the above modifications.

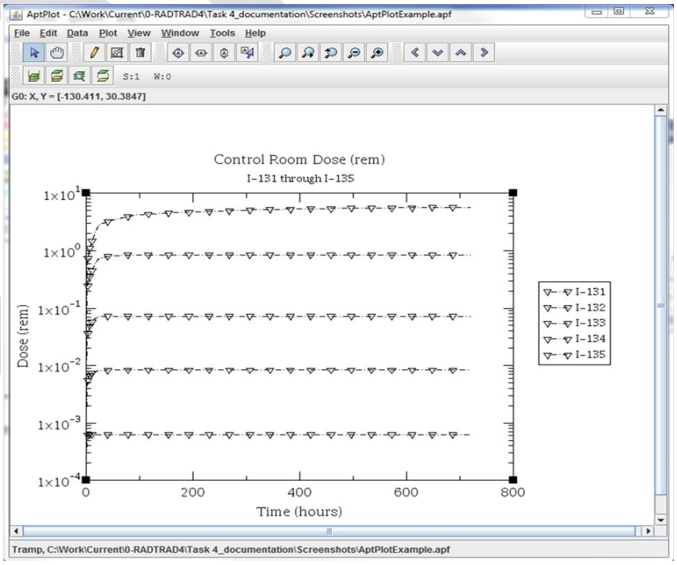

Figure 3-22 Reformatted control room dose plots for Test23

Note that plots can be generated in a picture format such as *.png* or *.jpeg* by navigating to *File->Print setup*. At the top of the *Device setup* window, change the device to *.png* for example. In the *Output* section, check that the directory path and filename are suitable. Then, click on the *Print* button and the plot will be saved in *.png* format using the filename set for the plot file.

For those users who wish to use a spreadsheet for data analysis or for plotting, the dose data can be exported. The easiest way is to initiate a new plot session in a comma-delimited format that can be read by Microsoft Excel. This feature is accessed from the *Select EXTDATA Channels* window. As an example, set up and apply a filter for the I-131 to I-135 thyroid dose in the control room and select the resulting data channels as done previously. Then, highlight the data channels and click on the *Export* button at the bottom of the window. A *Save* window will appear. Provide a filename, ending the filename with the *.csv* suffix and select comma separated values (CSV) as the file type (right hand side of the *Save* window). Then, click on *Save* to write the file. Microsoft Excel will read and organize the dose data by column for subsequent use.

3.3 SNAP/RADTRAD Model Development and Modification

Sections 3.1 and 3.2 introduced the SNAP/RADTRAD Model Editor user interface using Test Problem 23 as an example. In this section, the details of building a new model are presented. For this illustration, a model consisting of a simple containment compartment, leakage pathway, source and an environment compartment will be developed.

3.3.1 Model Editor Menus

The commands available in the Model Editor are typical of Windows programs. Across the top of the Model Editor, the *File*, *Edit*, *Tools*, *Window*, and *Help* commands are presented. Table 3-2 describes the commands associated with each of these menu items.

Table 3-2 Summary of Model Editor menu commands

Menu Command	Description
File Commands	
File->New	Creates a new model. A Select Model Type menu appears with available models listed. The SNAP/RADTRAD user picks *RADTRAD* and clicks on the *OK* button.
File->Open	Opens a previously developed model (*.med file*). The user navigates to the directory where the file is located and selects the file to be opened similar to any Windows program.
File->Open Recent	Allows the user to open a recently used SNAP/RADTRAD model (or AVF file). The user selects the file of interest and it will open in a new Model Editor session.

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Menu Command	Description
File->Save	Saves the current model with the same name as in any Windows program.
File->Save As	Saves the file under a new filename. The user navigates to the desired directory location and/or updates the filename and clicks the *Save* button as in any Windows program.
File->Close	Closes the current model. Provides a warning to the user in the case of any unsaved changes made to the model.
File->Close All	Closes multiple open models. Provides a warning to the user in the case of any unsaved changes made to the model.
File->Import	Imports a previously exported RADTRAD model from a set of ASCII or XML input files (see Section 3.2.3). Note that a *.psf* file is an ASCII file with the same input data as the XML formatted *.psx* files.
File->Export	Exports a set of SNAP/RADTRAD XML input files (*.psx*, *.nix*, *.srx*, *.icx*, and *.dfx*) to a directory selected by the user (see Section 3.2.3).
File->Exit	Exits the Model Editor.
Edit Commands	
Edit->Undo	Reverses previous user inputs to a model similar to any Windows program.
Edit->Redo	Redoes a previous undo command similar to any Windows program.
Edit->Preferences	Allows the user to set various preferences related to fonts, colors, and other Model Editor features.
Edit->Plugin Manager	Allows enabling and disabling of various plugins. Generally not used for SNAP/RADTRAD.
Tools Commands	
Tools->Check Model	Provides a check of the SNAP/RADTRAD input model. This feature is very useful for model development in SNAP/RADTRAD.
Tools->Submit Job	Submits a job through the job stream and starts the *SNAP Job Status Tool* (see Section 3.2.2).
Tools->Steam Tables	Not used in SNAP/RADTRAD.
Tools->Configuration Tool	Starts the SNAP/RADTRAD *Configuration Tool* (see Section 3.1).
Tools->Job Status	Starts the SNAP/RADTRAD *SNAP Job Status* window (see Section 3.2.2).
Tools->Model Note Viewer	Displays model notes. The user can set up and edit notes as part of the model documentation.

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Menu Command	Description
Tools->Export to jEdit	Exports a model to the jEdit editing program. This feature requires the installation of jEdit.
Windows Commands	
Windows->Commands	*Scripting commands* window – not used in SNAP/RADTRAD.
Help Commands	
Help->Contents	Link to the SNAP Model Editor manual, which includes information about the RADTRAD Plugin.
Help->Check for Updates	Checks for updates at the APT, Inc. website. Note that computer security settings may inhibit this feature.
Help->Report an Issue	Allows the user to submit Issue Reports on SNAP/RADTRAD directly to APT, Inc. Note that issues related to the RADTRAD-AC should be reported via email to RADTRAD_Help@nrc.gov.
Help->About	Provides information on the SNAP GUI and Plugin version, licensing agreements, and contact information. Note that plugin version numbers can be obtained by clicking on the *Plugins* button.

Figure 3-23 shows the icon arrangement and function of each icon in the Model Editor. Of particular interest is the ability to separate the *Navigator*, *Property*, and *View / Dock* windows into separate windows and to also arrange the windows vertically by clicking on the *Single/Multiple Windows Modes* icons shown in Figure 3-23. The remaining icons provide a shortcut to some of the menu commands listed in Table 3-2.

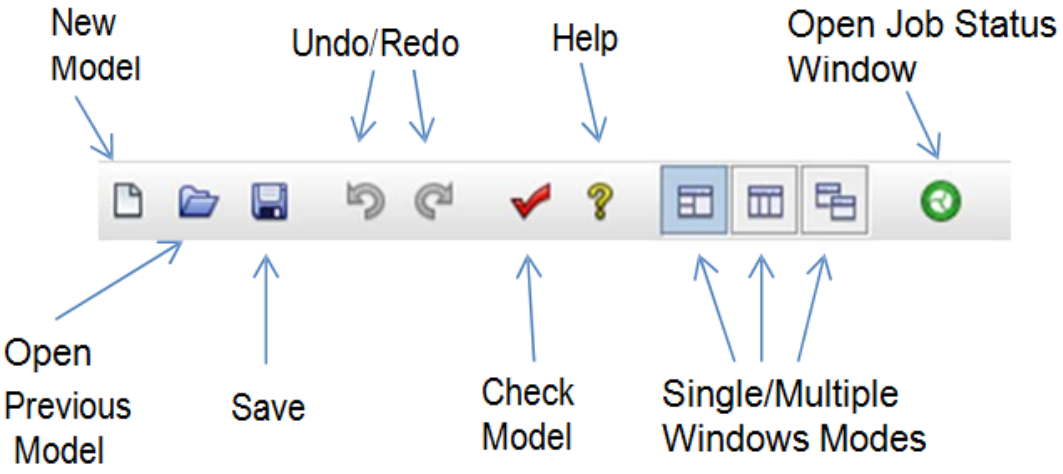

Figure 3-23 Model Editor tool bar icon description

Figure 3-24 shows the icon arrangement and the function for each icon in the *Navigator* window. Basically, these tools aid the user in navigating component nodes in the *Navigator* window and multiple models in the SNAP GUI.

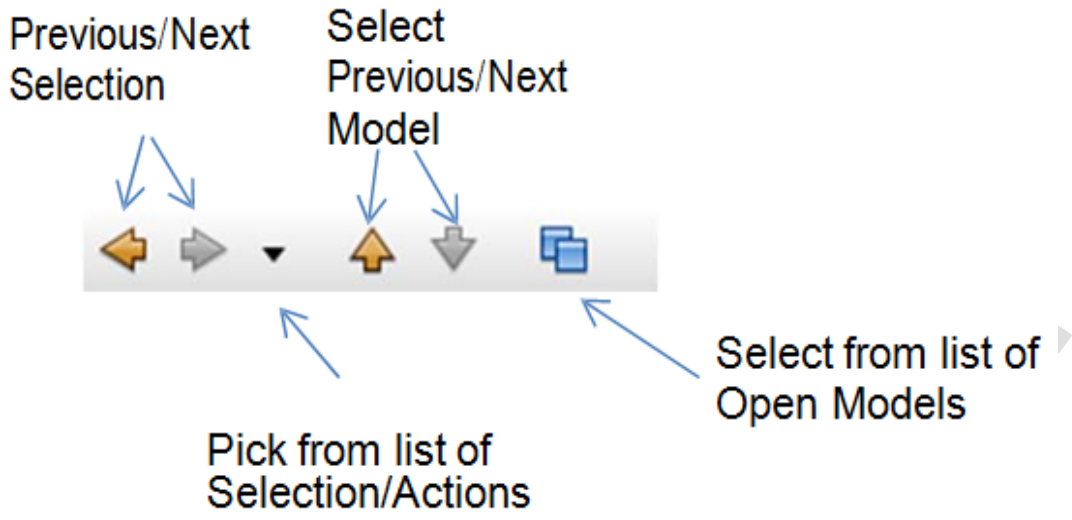
Previous/Next Selection
Select Previous/Next Model
Select from list of Open Models
Pick from list of Selection/Actions

Figure 3-24 Navigator window tool bar icon description

3.3.2 Building a SNAP/RADTRAD Model – Component Specification

The first step is to start the SNAP Model Editor and click on *Create a New Model* in the *Welcome* screen (Figure 3-1). Select *RADTRAD model* in the *Select Model Type* screen that subsequently appears similar to Figure 3-2 except there are no icons in the *View / Dock* window. The basic model nodes are shown in the *Navigator* window. Expand the *Compartment [1]* node using the *Expand* ( ) icon in the *Navigator* window. Highlight (click on) the *Compartment 1 (Environment)* node, so that data fields for this compartment will appear in the *Property* window. Note that an environment compartment is defined by default.

The basic approach to building a SNAP/RADTRAD model is to set up an array of compartments, flow pathways and specify key parameters in the various components of the model. For sources, compartments, and pathways that ultimately appear in the *View / Dock* window, the basic pattern is to highlight (select) the component category (i.e. *Source*, *Compartments* and *Pathways*), right-click on the component category, and select *New* from the menu to add a numbered component to that component category. These steps result in a new model component being created.

A new compartment is added by right-clicking on the *Compartment* node in the *Navigator* window and selecting *New* in the menu that appears. A new compartment component *Compartment 2* is created. Components are not automatically added to the *View / Dock* window, but must be added by the user. The new component (*Compartment 2*) is added to the

View / Dock window by right-clicking on the *Compartment 2* and selecting *Add to View->Default View*. *Compartment 2* now appears in the *View / Dock* window.

The new component (*Compartment 2*) is unnamed. To add a name to the component, type a name (i.e. Containment) in the *Name* text box in the *Property* window. The name will simultaneously appear in both the *Navigator* and *View / Dock* windows [Compartment 2 (Containment)]. Alternately, newly-defined components can also be dragged from the *Navigator* window to the *View / Dock* window by clicking on the component of interest and dragging it by holding the left mouse button down and moving the cursor to the *View / Dock* window.

The pre-defined *Environment* compartment is added to the *View / Dock* window in a manner similar to *Compartment 2 (Containment)* above. Right-click on *Compartment 1 (Environment)* and select *Add to View->Default View* or drag the component by clicking on the new component node and dragging it into the *View / Dock* window. The environment compartment will appear in the *View / Dock* window. Note that two dose locations (EAB and LPZ) are automatically specified with the environment compartment.

The next step is to define a flow pathway which is done by right-clicking on the pathway group node (*Pathways [0]*) and selecting *New* in the menu that appears. *Pathway 1* appears. Add *Pathway 1* to the *View / Dock* window by right-clicking on *Pathway 1* and then selecting *Add to View Default View* as was done above. The flow pathway should be named by entering a suitable name in the *Name* text box in the *Property* window (i.e. *Leakage*).

Similarly a source can be added by right-clicking on the *Sources* node in the *Navigator* window (*Sources [0*]) and selecting *New*. After naming the component (i.e. *Fuel Release*), the component can be added to the *View / Dock* window in the same manner as used above for compartments and flow pathways.

At this point, the user can see that a pattern is emerging. Each input group has an associated group node where components within that group can be defined and added to the *Navigator* window. Figure 3-25 displays the *Navigator* window for the components added in the previous steps above. The component nodes that can be added as part of a model are: *Sources*, *Compartments*, and *Pathways*. The nodes for *Dose Locations*, *Natural Deposition*, *Filters*, *Sprays*, and *X/Q Tables* are not drawn, but are defined in the same manner as compartments, pathways, and sources by right-clicking on the component group node and selecting *New*.

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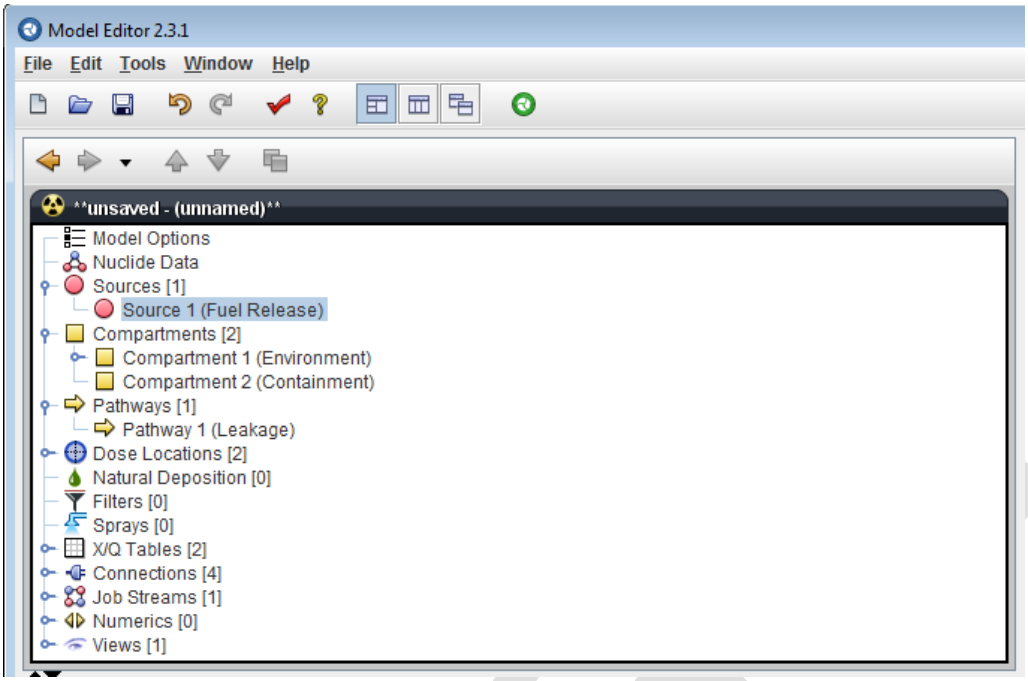

Figure 3-25 Navigator window with newly added model components

At this point, the user has developed a new model consisting of a source, a compartment representing the containment, a leakage pathway and an environment compartment. Also, this new model was added to the *View / Dock* window by either dragging the new component node to the *View / Dock* window or right-clicking on the new component node, then selecting *Add To View*. Figure 3-26 shows the *View / Dock* window with the new model's components. Additionally, once the components are added to the *View / Dock* window, they will be needed to be moved around for presentation clarity. Make sure the *Selection Tool* ( ) icon is activated before rearranging the icons in the *View / Dock* window. Features common to most Windows-based programs are available to aid the user in editing and arranging icons. The function of each icon can be determined by hovering the mouse pointer above the icon of interest. This action should cause a text pop-up to appear with a short statement of the function of that icon. The tools and features most commonly used in SNAP/RADTRAD are illustrated in Section 3.3.4.

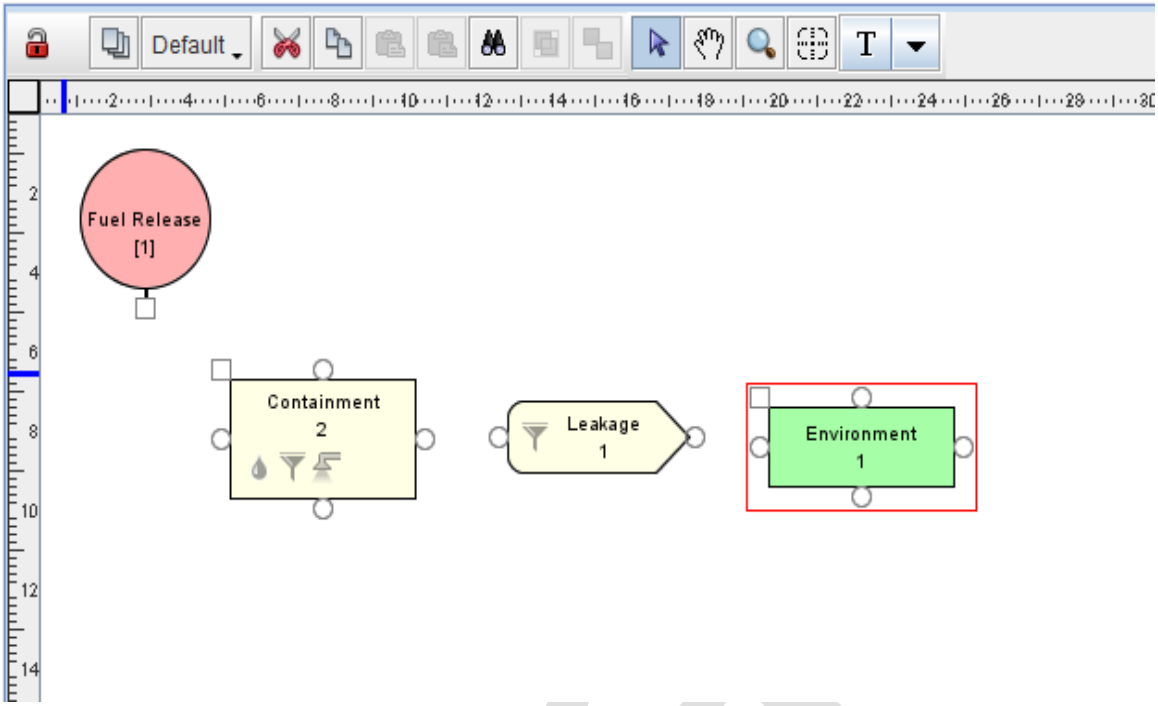

Figure 3-26 View / Dock window for 4-node model (unconnected)

Table 3-3 shows all of the icons which are available in the *View / Dock* window with a description of each icon. All of the icons for the compartments, sources and pathways have connection points for connecting flow pathways and source components to compartment components as illustrated in Figure 3-26. The number in the different icons in Figure 3-26 are the component number, which are generally consecutive in SNAP/RADTRAD models.

One feature that the user should be aware of is the orientation feature for flow pathway icons. In Figure 3-26, the orientation is pointing right; however, the orientation can be changed to pointing up, pointing down, or pointing left by right-clicking on the flow pathway icon and selecting *Drawn Orientation* from the menu that appears and then pick the desired orientation.

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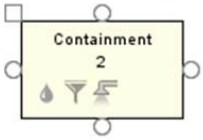
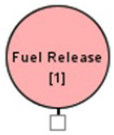
Table 3-3 Icons used in the View / Dock window

View / Dock Window Icons	Description
 Compartment Icon	Flow pathway connection point indicated by small circles on each edge. Small square at the upper-left corner is a source connection point.
 Source Icon	Small square at the lower edge is a source connection point to a compartment.
Flow Pathway Icon	Flow pathway connection point indicated by small circles on each side.
Environment Icon	Flow pathway connection point indicated by small circles on each edge. Small square at the upper-left corner is a source connection point.
	Icon denoting that natural deposition is active in a component (grayed-out indicates inactive).
	Icon denoting that a filter is defined in a component (grayed- out indicates no filter).
	Icon denoting that a spray is defined in a component (grayed-out indicates no spray).

The next step is to connect the components using the *Connection Tool* (⊞) icon shown in the *View / Dock* window tool bar (see Section 3.3.4). Connection points for the various icons are shown in Figure 3-26. The first step is to click on the *Connection Tool* (⊞) icon in the *View / Dock* window tool bar, which activates the connection tool. Then for compartment to flow pathway connections, click on the connection point (circle) on the edge of the compartment to be connected and drag holding the left mouse button down to the desired connection point (circle) on the flow pathway icon and release the button. The procedure is the same for the source to compartment connections except the connection points denoted by squares are used. Figure 3-27 shows the model with the connections made.

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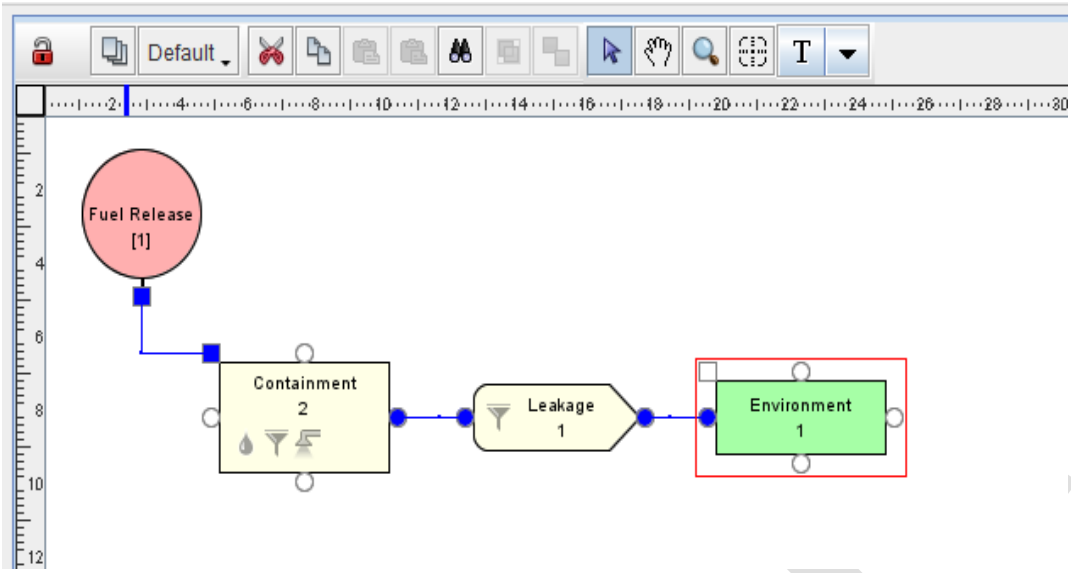

Figure 3-27 View / Dock window for 4-node model (connected)

The expanded node view of the *Navigator* window corresponding to the model in Figure 3-27 is shown in Figure 3-28. Figure 3-28 shows all of the connections for all of the components shown in the model. Basically, it is an expanded node view of the schematic representation shown in Figure 3-25. Users should get into the habit of naming the various components of their models. This practice will help avoid errors, particularly as models get more complicated.

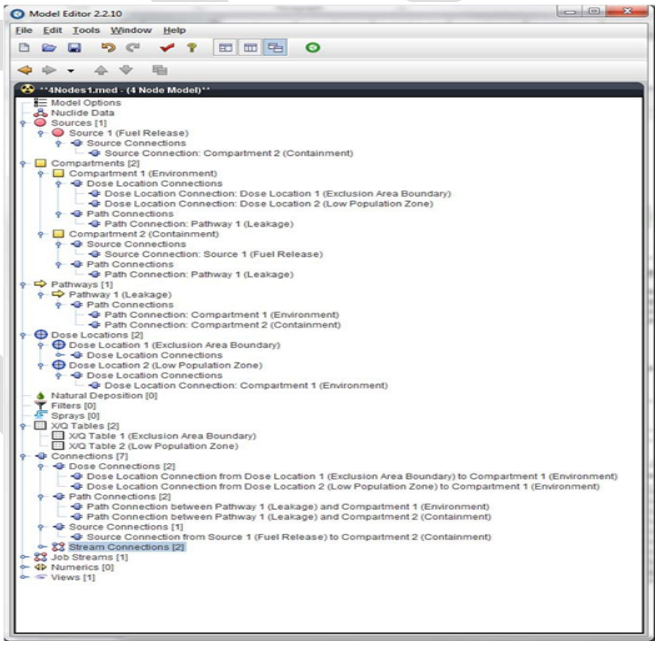
Model Editor 2.2.10
File Edit Tools Window Help
4Nodes1.mod - (4 Node Model)
Model Options
Nuclide Data
Sources [1]
Source 1 (Fuel Release)
Source Connections
Source Connection: Compartment 2 (Containment)
Compartments [2]
Compartment 1 (Environment)
Dose Location Connections
Dose Location Connection: Dose Location 1 (Exclusion Area Boundary)
Dose Location Connection: Dose Location 2 (Low Population Zone)
Path Connections
Path Connection: Pathway 1 (Leakage)
Compartment 2 (Containment)
Source Connections
Source Connection: Source 1 (Fuel Release)
Path Connections
Path Connection: Pathway 1 (Leakage)
Pathways [1]
Pathway 1 (Leakage)
Path Connections
Path Connection: Compartment 1 (Environment)
Path Connection: Compartment 2 (Containment)
Dose Locations [2]
Dose Location 1 (Exclusion Area Boundary)
Dose Location Connections
Dose Location 2 (Low Population Zone)
Dose Location Connections
Dose Location Connection: Compartment 1 (Environment)
Natural Deposition [0]
Filters [0]
Sprays [0]
X/Q Tables [2]
X/Q Table 1 (Exclusion Area Boundary)
X/Q Table 2 (Low Population Zone)
Connections [7]
Dose Connections [2]
Dose Location Connection from Dose Location 1 (Exclusion Area Boundary) to Compartment 1 (Environment)
Dose Location Connection from Dose Location 2 (Low Population Zone) to Compartment 1 (Environment)
Path Connections [2]
Path Connection between Pathway 1 (Leakage) and Compartment 1 (Environment)
Path Connection between Pathway 1 (Leakage) and Compartment 2 (Containment)
Source Connections [1]
Source Connection from Source 1 (Fuel Release) to Compartment 2 (Containment)
Stream Connections [2]
Job Streams [1]
Numerics [0]
Views [1]

Figure 3-28 Navigator window with all nodes expanded

3.3.3 Building a SNAP/RADTRAD Model – Input Specification

Input specification is the next step in developing a SNAP/RADTRAD model. The Model Editor design basically guides the user through the various input parameters required. Clicking on any of the defined compartments presents a list of input data that needs to be specified in the *Property* window. Also, an important feature in SNAP/RADTRAD is the ability to check the model using the *Check Model* feature which is found by either navigating to *Tools->Check Model*.

This illustration will start by completing the input for *Compartment 2 (Containment)* shown in Figure 3-27. The volume of this compartment will be set to 2.5E+06 ft^3. Note that the default units of the model are in SI. To switch units to English, right-click on the black bar in the *Navigator* window, select *Engineering Units->Britis*h to change the units. Figure 3-29 shows the location of the black bar and the accompanying menus. Once the units are switched, click on the *Compartment 2 (Containment)* icon in the *View / Dock* window or in the *Navigator* window and enter *2.5E6* in the *Volum*e text box in the *Property* window. Also check that the *Compartment Typ*e text box is set to *Normal*. Other compartment types are discussed in Section 3.3.4. Figure 3-30 shows the *Property* window with the volume set to *2.5E6*. Note that deposition, filter, and sprays models are not used.

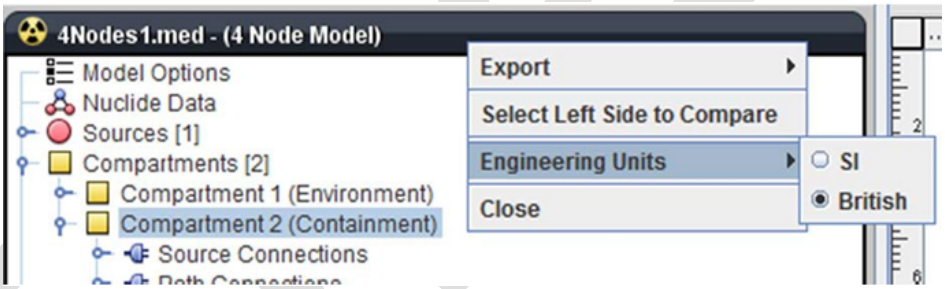

Figure 3-29 Navigator window with the black bar menu for the engineering units selection

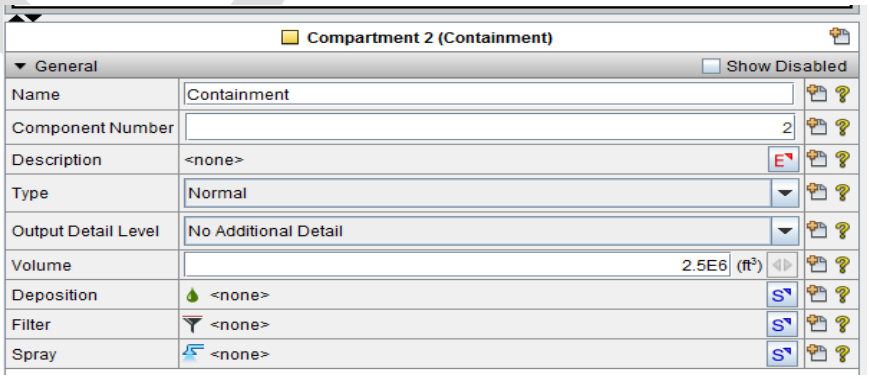

Figure 3-30 Property window with volume entry for the Compartment 2 (Containment)

Input for the flow pathway involves a data entry table to capture the time dependence of the assumed containment leakage rate of 0.1 percent per day (%/day). The first step is to change the Pathway Type text box in the *Property* window from *Piping* (default) to *Air leakage* (typically used for containments). Next, specify a leakage rate by clicking on the *Custom Editors* (E) icon adjacent to the *Leakage Rate* text box to open the *Editing Leakage Rate* window Figure 3-31. A data entry table window will open, which is one of the most common ways to specify input entries in SNAP/RADTRAD.

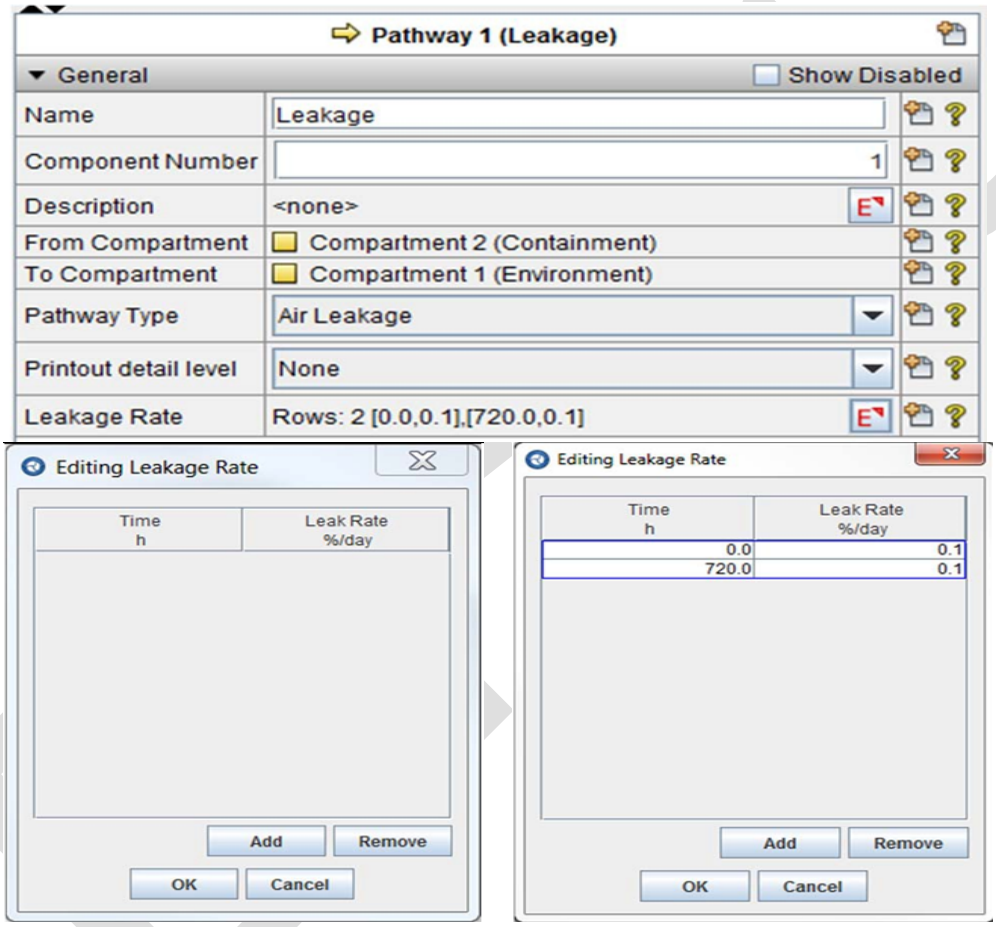

Figure 3-31 Pathway input windows for sample problem

The user can click on the *Add* button and add a leakage rate of 0.1 %/day for 0 to 720 hrs. Two rows will be needed. Some users prefer to set up the number of rows needed for the data while others add a new row after each set of data entries are completed. To delete a row, highlight the row to be deleted and click on the *Remove* button.

The next step is to specify the X/Q tables. The X/Q values used for this illustration are listed in Table 3-4. The approach is basically the same as that used for the flow pathway input. The first step is to click on the *Expand* ( ) icon next to the *X/Q Tables* node in the *Navigator* window,

then click on *X/Q Table 1 (Exclusion Area Boundary)* node. In the *Property* window for the *X/Q Table 1 (Exclusion Area Boundary)* click on the *Custom Editors* ( ) icon adjacent to the *X/Q Table* text box to open the *Editing X/Q Table* window Figure 3-32. As in the case of the leakage rate above, the user can enter data in a new table by clicking on the *Add* button and adding the values shown in Table 3-4. Using the *Add* and *Remove* buttons, the X/Q values for the EAB and LPZ can be completed by the user. Figure 3-32 shows the completed X/Q tables.

Table 3-4 Sample problem X/Q values

Time Interval (hrs)	X/Q Value by Location (sec/m^3)	
	EAB	LPZ
0 – 2	1.4E-04	4.5E-05
2 – 8		2.39E-05
8 – 24		1.29E-05
24 – 96		5.49E-06
96 – 720		1.61E-06

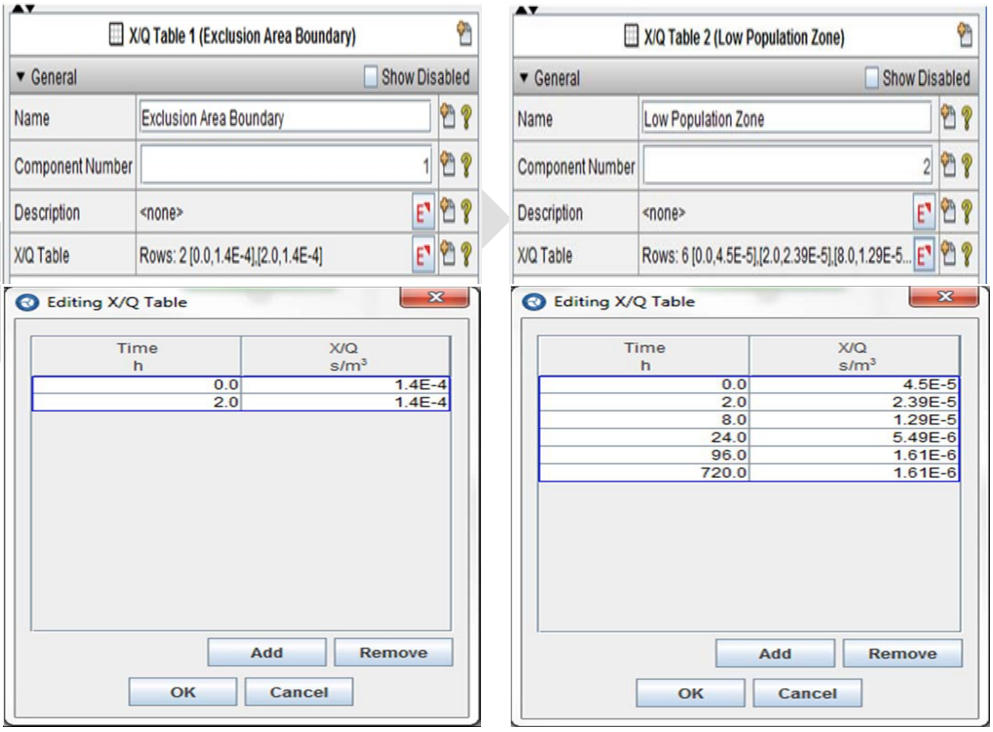

Figure 3-32 X/Q input tables for EAB (left) and LPZ (right)

The final item to be completed is the source term specification. The source term specification consists of two parts. The first part is to specify the radionuclide inventory in the fuel or reactor coolant and the second is the source or release fraction scenario specific to the accident type. Both combine to generate the radionuclide inventory to determine an overall source term. Additionally, there is also the setting for core power in the *Model Options* node that is used to determine the radionuclide inventory.

There are two default core inventory libraries (PWR and BWR), which are not editable by the user, which are used to determine the core inventory.

- PWR – normalized Methods for Estimation of Leakages and Consequences of Releases (MELCOR) Accident Consequence Code System (MACCS) sample 3412 megawatt thermal (MWth) PWR core inventory (60 nuclides).
- BWR – normalized MACCS sample 3578 MWth BWR core inventory (60 nuclides).

Basic editing features for the *Edit Total Inventories* window are shown in Figure 3-33. These features can be used to either edit an existing file or specify a new inventory file. For example, the PWR inventory file can be duplicated by selecting the PWR inventory and then clicking on the *Copy Existing File* ( ) icon which will make a duplicate and append a number to the file that can then be renamed by the user. Once a copy is made, the data becomes editable. Nuclides can be added, deleted, and rearranged using the *Nuclide Editing Tools* shown in Figure 3-33. In addition, nuclide files can be exported and imported.

For this illustration, the generic PWR inventory with a core power level of 3637 MWth and the alternative source term release fractions from Regulatory Guide 1.183 (RG 1.183), “Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors” [8] will be demonstrated. The source specification steps are as follows:

- Left-click on *Model Options* node in the *Navigator* window, locate the *Plant Power Level* text box in the *Property* window and set the plant power level to *3637* MWth.

- Expand the *Sources [1]* node and left-click on *Source 1 (Fuel Release)*, locate *Source Scenarios* text box in the *Property* window and left-click on the *Custom Editors* ( ) icon. In the *Edit Total Inventories* window, add a new scenario by clicking on the *New* ( ) icon. When the *Select from Total Available Inventories* window opens select *PWR* and enter the name *PWR Source* in the *Scenario Name* text box. Also, note that the *Active Scenario* name changes to *PWR Source*.

- Under the *Accident Parameters* tab, the pick *DBA AST* under the *Accident Type* dropdown menu and select the *PWR* button under *Defaults Type* (see Figure 3-34).

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- At this point, the user should review the data comprising the source term by clicking on each tab in the *Edit Total Inventories* window and noting the progression of the calculations leading to the total source term definition.

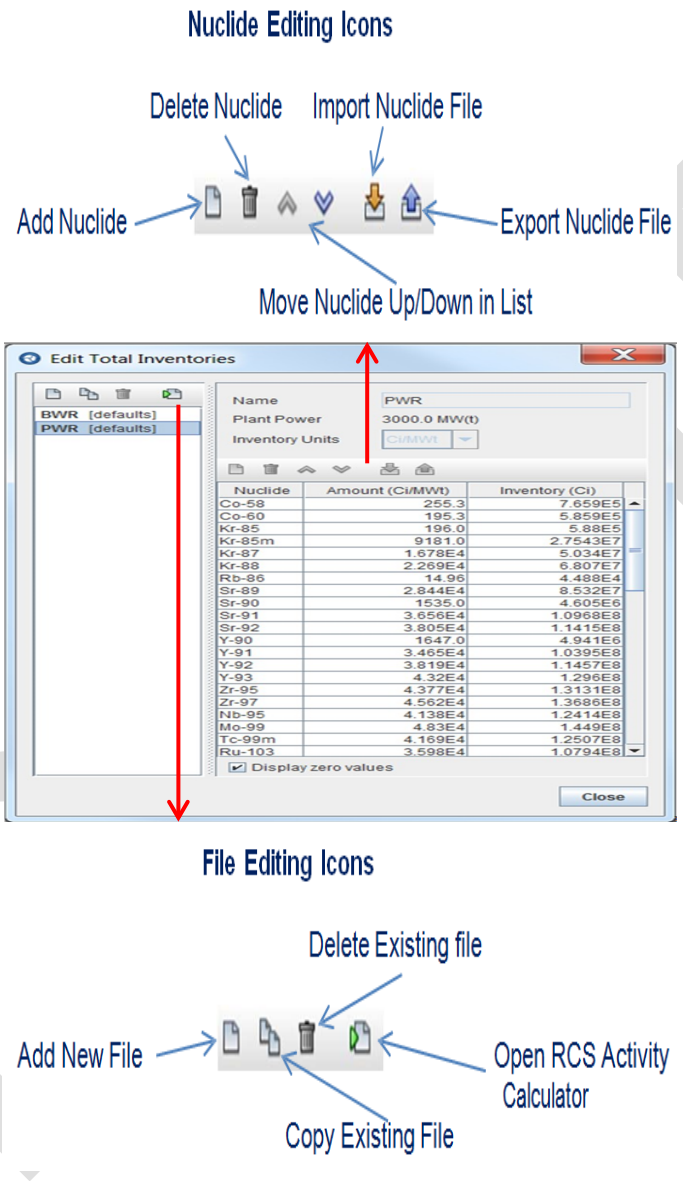

Figure 3-33 SNAP/RADTRAD Edit Total Inventories window editing features

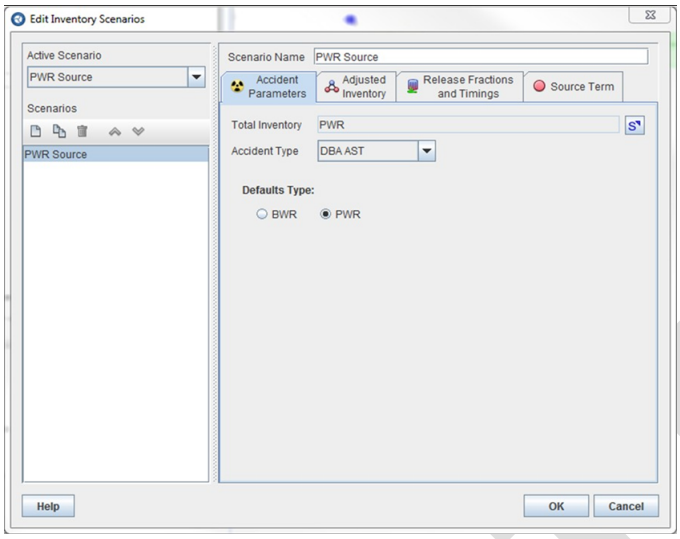

Figure 3-34 Edit Total Inventories window Accident Parameters tab

- Clicking on the *Adjusted Inventory* tab will list the core inventory based on the generic PWR file. Note in Figure 3-35 that there are two columns. The column labeled *Amount* lists the activity in curies (*Ci)/MWth* and the column labeled *Inventory* lists the total activity in *Ci*. Note that the inventory is calculated from the amount using the *Plant Power Level* set previously in the *Model Options* node.

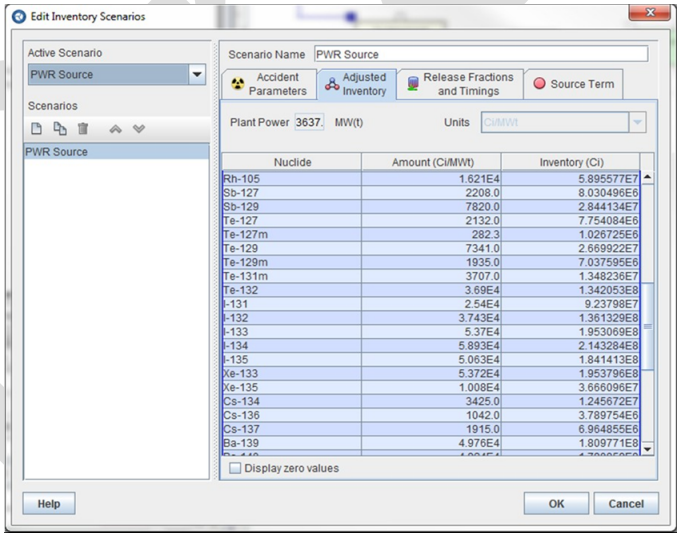

Figure 3-35 Edit Total Inventories window Adjusted Inventory tab

- Clicking on the *Release Fractions and Timings* tab lists the release fractions from Table 2 of RG 1.183 (see Section 4.3). The *Release Durations (hrs)* are also listed and are

from Table 4 of RG 1.183. Note that the *Ex-Vessel* and *Late* release values for each are not used in SNAP/RADTRAD and are always set to *0.0* (see Figure 3-36).

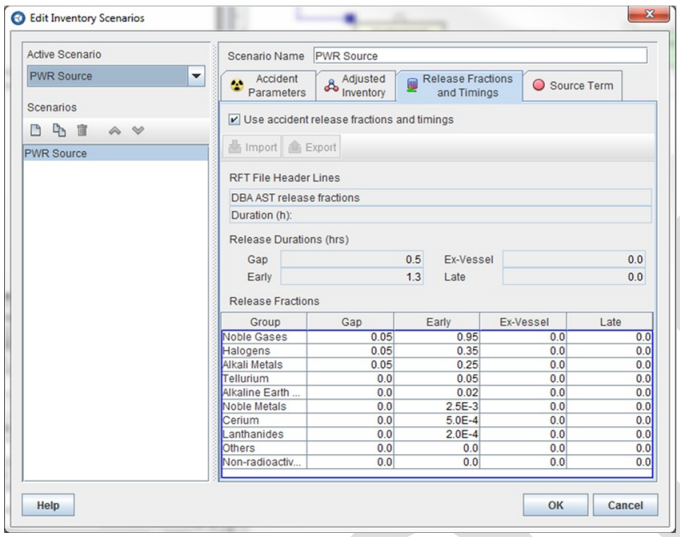

Figure 3-36 Edit Total Inventories window Release Fractions and Timings tab

- Finally, clicking on the *Source Term* tab shows the calculated source term associated with the particular nuclide as shown in Figure 3-37. Further discussion of source term modeling in SNAP/RADTRAD is presented in Sections 3.4.

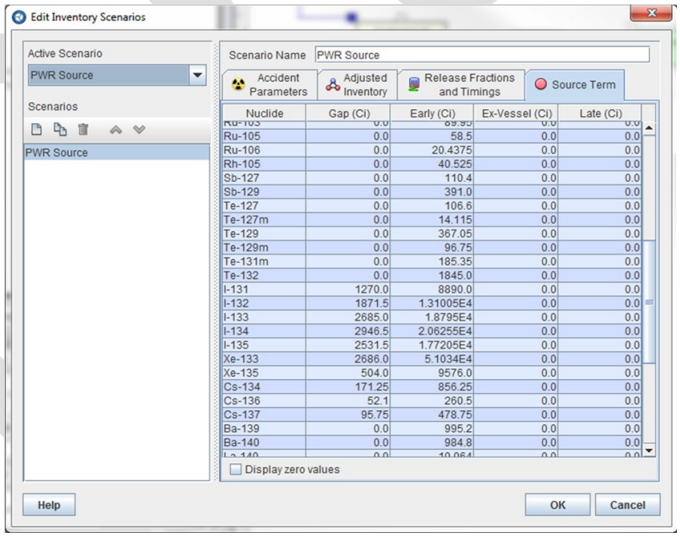

Figure 3-37 Edit Total Inventories window Source Term tab

The final step for the source term specification is to set the source term fraction and the iodine chemical forms to the RG 1.183 (NUREG-1465) values. These values are set by using the

dropdown menu associated with the *Iodine Physical Form* text box in the *Property* window as shown in Figure 3-38. The aerosol, elemental and organic iodine fractions are listed but are not editable (grayed-out).

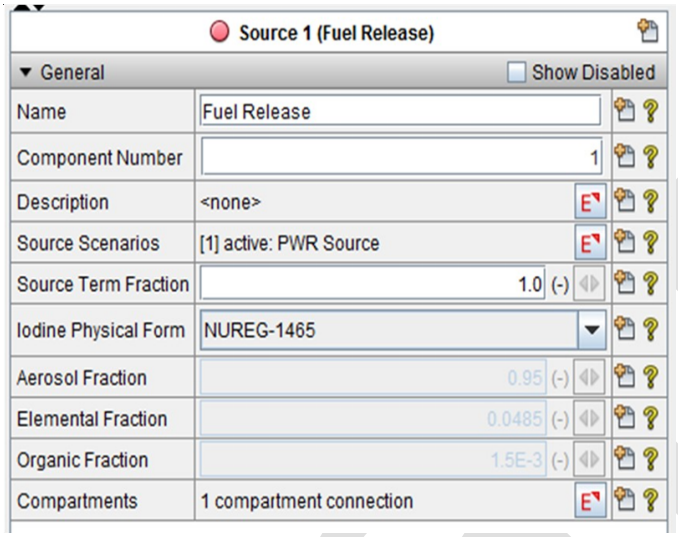

Figure 3-38 Property window for source term iodine chemical form settings

The user can now run a model check by navigating to *Tools->Check Model* and looking for the notes in the *Message* window in the lower part of the Model Editor indicating that no errors were found as shown in Figure 3-39. There are three icons to the right of the message window used to copy or delete messages.

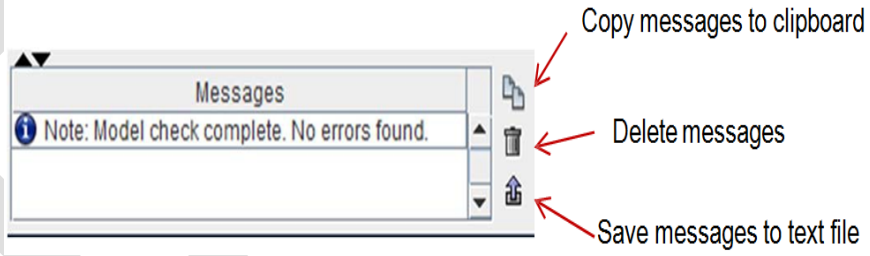

Figure 3-39 Model Editor Message window with icons

If an error is detected, an *Error Report* window appears listing the errors as shown in figure 3-40. The error messages, which are generally self-explanatory, provide a guide of what needs to be fixed. Note that there are other classifications of messages (*Notes*, *Alerts*, *Warnings*, and *Errors*). Generally, SNAP displays messages in these different classifications automatically. The goal for model development is to have no errors or warnings generated by SNAP/RADTRAD. Once error checking is complete and no errors or warnings exist in the model, the user can run the case as described in Section 3.2.2.

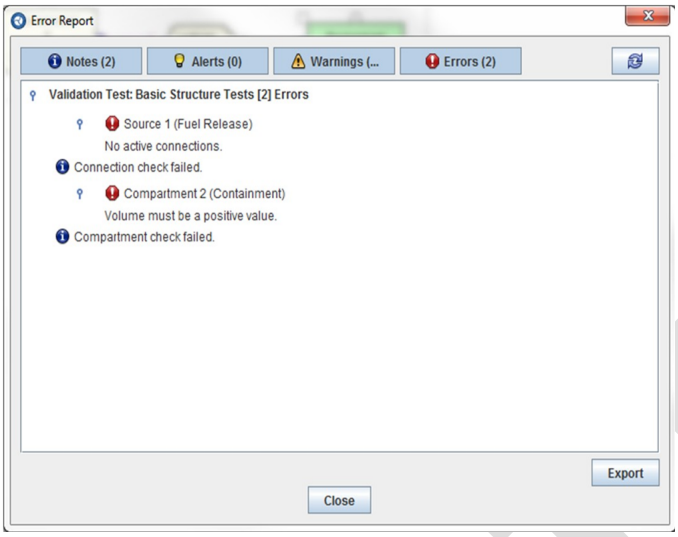

Figure 3-40 Model Editor Error Report window

3.3.4 Building a SNAP/RADTRAD Model – Additional Features

There are a number of features and icons in the *View / Dock* window that the SNAP/RADTRAD user should become familiar with for general model building as shown in Figure 3-41. These features include the *Cut* (), *Copy* () and *Paste* () icons which are used by selecting the icon (*Compartment*, *Pathway*, etc.) in the *View / Dock* window to be cut or copied, then clicking on the *Cut* () or *Copy* () icon and pasting it in the *View / Dock* window.

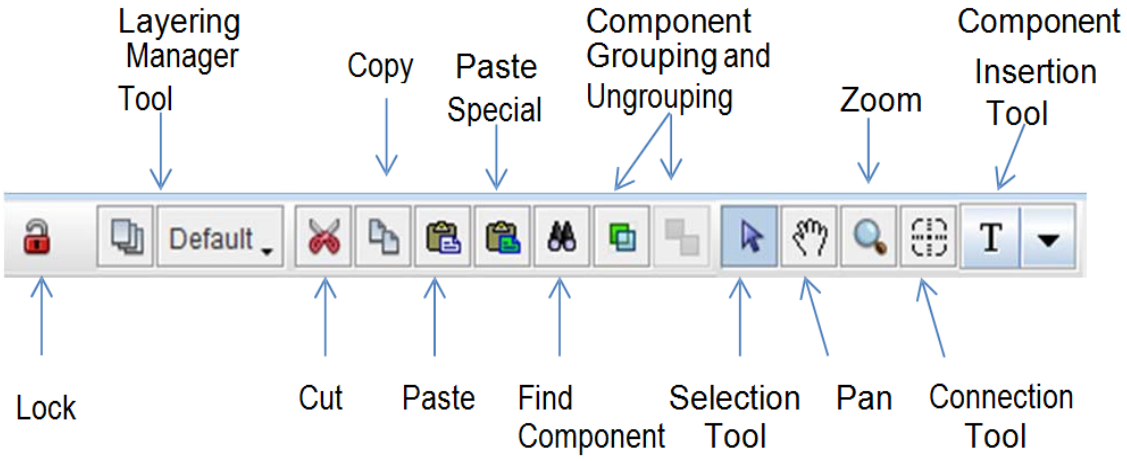

Figure 3-41 View / Dock window tool bar icons

The *Paste Special* () icon allows the user to paste multiple copies or to control component renumbering. The features of the *Paste Special* () icon are shown in Figure 3-42. The utility

of this tool is to maintain unique component numbers in the copy and paste process. To duplicate a component using the *Copy* (📋) icon and *Paste Special* (📋) icon, confirm the *Selection Tool* (↖) icon is activated (Figure 3-41) and then click on the component to be duplicated. Click on *Paste Special* (📋) icon and confirm that the numbering offset is selected, a value of 1 for the offset is fine. Then click on the *OK* button and the component will be duplicated.

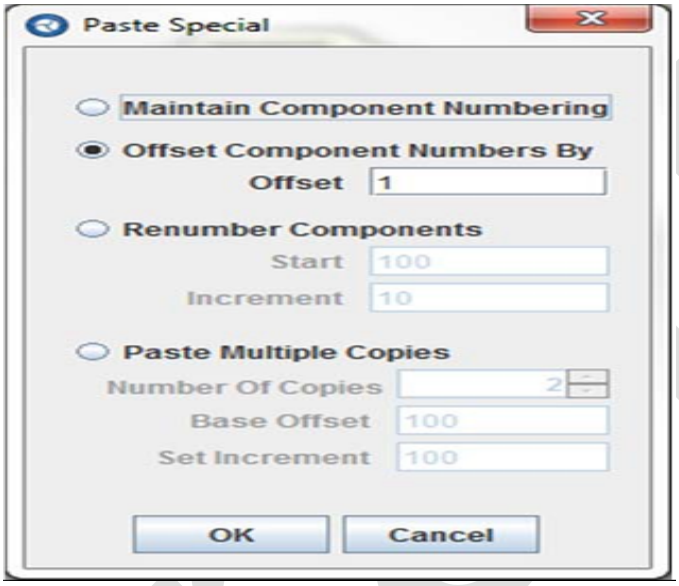

Figure 3-42 Features of the Paste Special Tool window

The *Selection Tool* (↖) icon, as the name implies, allow the selection of icons for copying. This tool needs to be activated as shown in Figure 3-41 to allow components to be selected or moved. A component is moved by clicking on the component and dragging it to the desired location by holding the left mouse button down. The *Find Component* (🔭) icon is used to find a component and it is usually used for large models with tens or hundreds of components and is typically not needed for SNAP/RADTRAD models.

Another very useful feature of SNAP/RADTRAD is the ability to group components (rubber band selection) and move them as a unit. The *Group* (📦) and *Ungroup* (📦) icons appear inactive (grayed out) until a group of components are defined. To define a component group, click the mouse button in an empty area of the *View / Dock* window, then drag the cursor around the group of components to be grouped (rubber banded) together. The *Group* (📦) icon, in Figure 3-41, will now become active. Click the *Group* (📦) icon to group the components together and note that the *Ungroup* (📦) icon the *View / Dock* window tool bar will become active. Clicking on the *Ungroup* (📦) icon ungroups the components in the previously defined group.

The *Zoom* (🔍) icon is used to zoom in on sections of a model. Clicking on the *Zoom* (🔍) icon and then clicking on the background of the *View / Dock* window will magnify the components.

Additionally, some useful features are available by right-clicking on the *View / Dock* window background while the *Zoom* ( ) icon is active which opens the *Zoom and Size* window shown in Figure 3-43.

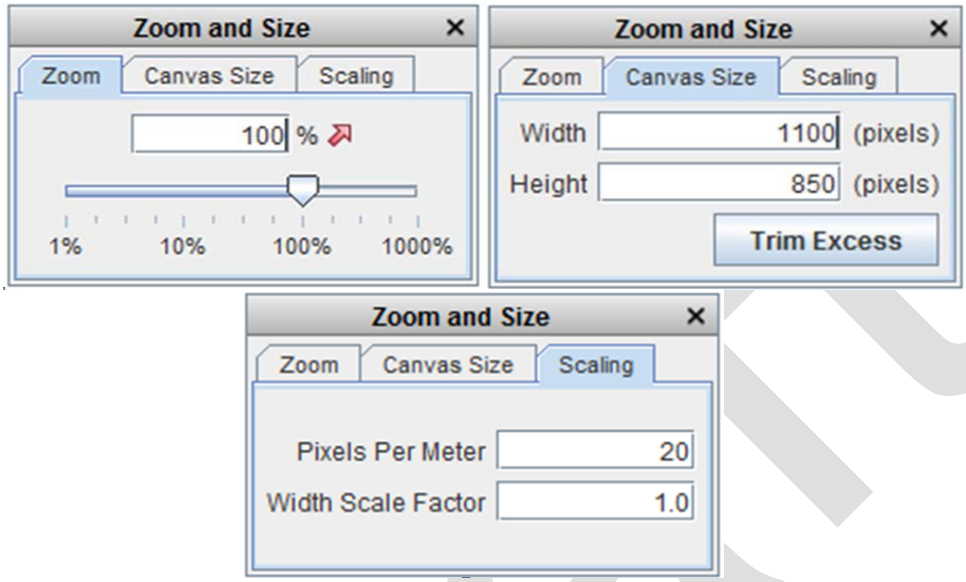

Figure 3-43 Zoom and size features

When the *Zoom* tab is activated, the zoom level can be set to any desired value by either using the slider or entering a number in the percent value in the text box. Note that clicking on the *red arrow* ( ) displays a dropdown list of preset values from which the user may make a suitable selection. When the *Canvas Size* tab is active, the width and height of the canvas can be set. The canvas is the portion of the *View / Dock* window surrounded by a red border on two sides and the scaling ruler on the remaining two sides of a model as illustrated in Figure 3-44. All component icons are rendered on the canvas and for larger models, sometimes the canvas borders cannot be seen. The *Zoom* ( ) icon can be used to shrink the model and bring the red borders into view. Also, if the canvas is larger than the model, clicking on the *Trim Excess* button will shrink the canvas area to fit the model.

In some SNAP models, the scale of icons is of interest to get a sense of perspective particularly for models where plant components are represented. Generally, SNAP/RADTRAD models are represented in a manner similar to a block diagram; however, a plant representation can be drawn using the *Component Insertion* ( ) icon on Figure 3-41.

Draft

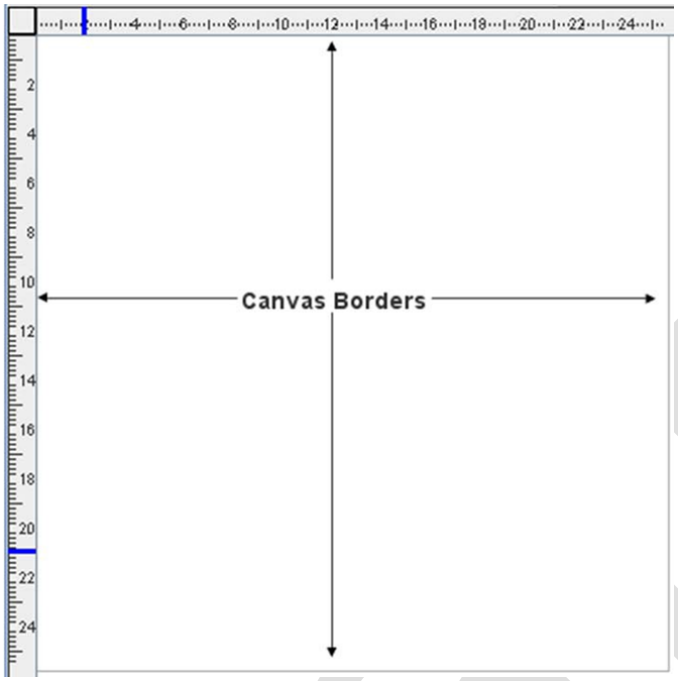

Figure 3-44 View /Dock window model canvas

SNAP/RADTRAD provides the feature of scaling meshes with some of the drawing features available using the *Component Insertion* ( ) icon. The *Component Insertion* ( ) icon allows the insertion of various components and basic drawing shapes into a model representation. Figure 3-45 displays the *Component Insertion* ( ) icon menus illustrating the available features. These menus are accessed by clicking on the dropdown arrow.

The features that would be most used in developing a SNAP/RADTRAD model would be the *Compartments*, *Sources* and *Pathways* Insertions. These three features make it easy to build a model by navigating the menus to the component of interest, clicking on that component, then moving the cursor to the *View / Dock* window and clicking again. This approach provides an alternative and is quicker than the approach involving right-clicking on the desired nodes in the *Navigator* window described earlier.

Draft

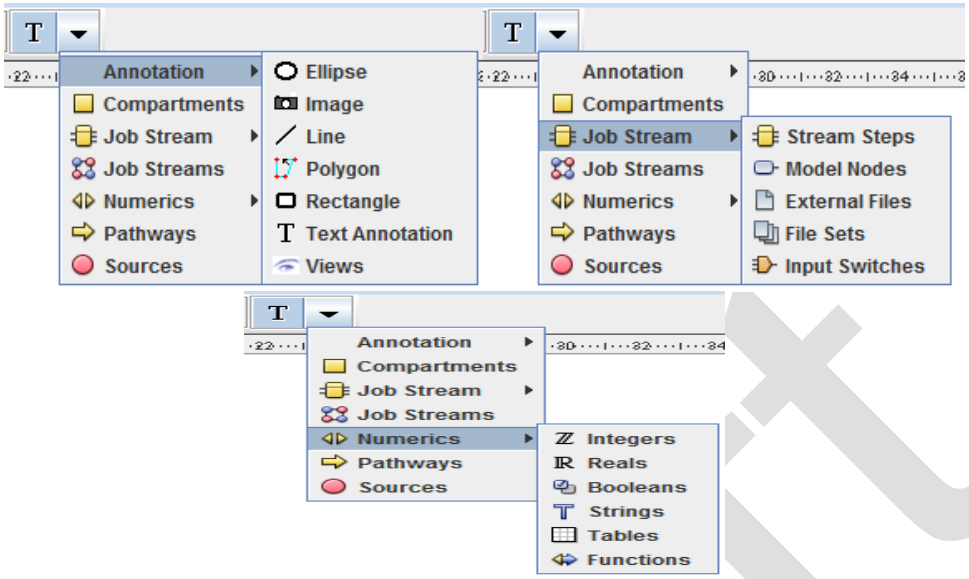

Figure 3-45 Component Insertion icon feature menus

The other feature that is useful is the ability to annotate a model using the *Annotation* feature. This *Annotation* feature allows the user to draw basic shapes and to add descriptive text. The basic approach is to navigate to the annotation feature of interest, select that feature and then click on the *View / Dock* window which will draw the selected icon. As an example, to draw an ellipse, navigate to *Annotation->Ellipse*, click on *Ellipse* in the menu, then move the cursor to the *View / Dock* window and click in that window to draw the selected shape. Right-clicking on the shape activates a menu that allows various drawing rendering features to be set. These features are typical of Windows-based drawing programs and are not discussed in detail.

The drawing features combined with scaling may be of interest to some users with an artistic tendency. When a new model is initiated, default values are set for the dimensions of the canvas which are a height of 850 pixels and a width of 1100 pixels. These values can be checked in the *Canvas Size* tab in the *Zoom and Size* window. The default scaling is 20 pixels per meter with a width scale factor of 1.0 which can be checked by clicking on the *Scaling* tab in the *Zoom and Size* window which is shown in Figure 3-43. Dividing the pixel values by the scaling factor yields a height of 42.5 meters and a width of 55 meters. Note that the ruler at the edge of the canvas shows these dimensions. Actually, units are immaterial in this context as the dimensions can be expressed in yards, feet or any other units. The scaling factor is actually the number of pixels per some unit of length.

Once a suitable scaling is set, scaled drawings representing plant components can be made using the annotation features discussed above. A sample is shown in Figure 3-46 in which a cylinder is scaled to be 100 feet in diameter and 100 feet high.

Draft

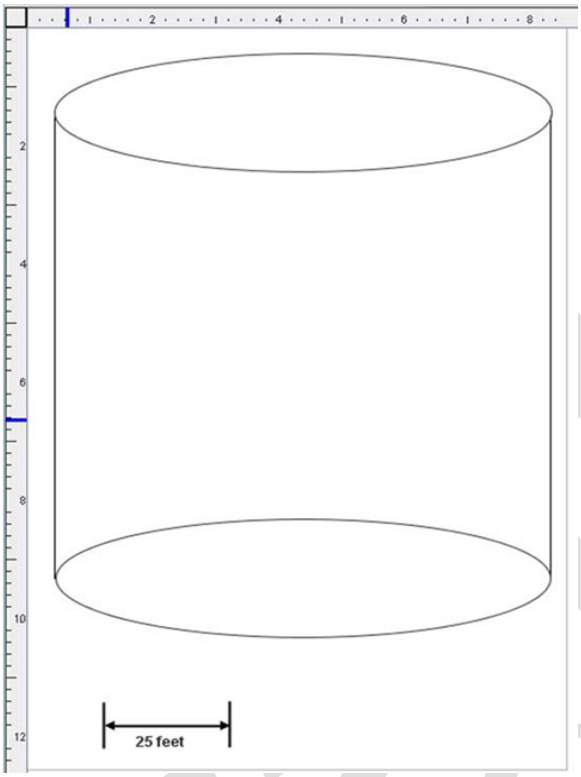

Figure 3-46 Cylinder drawn using the Annotation features of SNAP

It is noted that, in general, the icons used to represent various components in a SNAP/RADTRAD model are adequate for model presentation. These features are illustrated for those users who may want to explore and use these features for additional model annotation.

3.4 SNAP/RADTRAD Input Summary

Up to this point, the user has seen the various approaches to specifying input in SNAP/RADTRAD. The first step is to define a component (compartment, flow pathway, dose location, etc. using the right-click and left-click sequences shown earlier) and then specifying the actual input parameters using drop menus, text boxes, and input tables. However, up to this point, many of the available input parameters have not been discussed.

Tables 3-5 through 3-15 present a summary of all of the inputs that can be specified in a SNAP/RADTRAD model. The organization of the tables follows the group node organization in the *Navigator* window. Summary explanations of the input requirements are provided. In addition, screenshots are provided to help orient the user and to provide context with the input. Comments are also provided to aid the user in specifying input.

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SNAP/RADTRAD input is largely self-explanatory given that the user has some dose analysis background. However, the user should be aware of the relationships among some of the group nodes from an input specification perspective. These relationships are as follows:

- general model options (Table 3-5);
- nuclide data and sources for specifying source terms (Tables 3-6 and 3-7);
- compartments, pathways, natural deposition, filters and sprays (Tables 3-8 through 3-12); and
- dose locations, breathing rates, and X/Q tables (Tables 3-13 and 3-14).

The relationships will become obvious as the user works with the SNAP Model Editor. Sometimes the relationship is "one way." As an example, the user can tell which X/Q table is linked to a particular dose location by clicking on one of the *Dose Location* nodes. However, if the user clicks on a particular *X/Q Table* node, the associated dose location is not readily identified. Hence, it is important to name the various model components to keep track of associations.

3.4.1 Model Options

Model options are applied to the overall problem. Some general comments on model options are listed below:

- *Plant Power Level* needs to be specified as it is used to determine the overall inventory in the source term calculation.
- Either *Decay* or *Decay with daughter* production should be used for most problems.
- The *Onset of Gap Release* and the *Start of Accident* should be set to *0.0*. Otherwise the simulation time is advanced which means that the lookup time for X/Q, breathing rate, occupancy factor and other time-dependent parameters is advanced which is incorrect.
- An *Adaptive Time Step* algorithm and a *Default with Error Calculation* options have been added to SNAP/RADTRAD.
- Options are provided to reduce the volume of output in the *Output Parameters* and *NRC Output Flags Property* window if the user desires to reduce the volume of output data.

Otherwise, the use of the default values should be acceptable for most problems, but should be checked by the user. It is easy to gloss over pre-defined inputs with programs like SNAP/RADTRAD.

Note that the values of the *Onset of Gap Release* and the *Start of the Accident* should remain at *0.0*. If values greater than *0.0* are used, the problem time is advanced by the specified value which causes the lookup values for time-dependent data such as X/Q to be later than it should be. This issue will be addressed in future versions of the RADTRAD-AC. Table 3-5 lists the available input for the *Model Options* node in SNAP/RADTRAD.

Draft

3.4.2 Adaptive Time Step

Generally, the default time step algorithm is adequate for most RADTRAD calculations. If the user wants to determine if there are time step sensitivities then two options are available:

1. *Default with Error Calculation*, and
2. *Adaptive Time Step*.

Error in the dose calculation can be determined by selecting the *Default with Error Calculation* option. The results can be view using the *AptPlot* program. Search for *error* or *error.scaled* to see the error results. To use the adaptive time step algorithm, select *Adaptive in the Time Step* option from the drop down menu.

The adaptive time step algorithm is new in SNAP/RADTRAD and it is considered to be experimental. Use of this algorithm adds a significant amount of running time to the problem. It is suggested that the user set up the problem using the *Default* time step algorithm option and the check for any time step sensitivities for the final runs using the *Default with Error Calculation* or *Adaptive Time Step* algorithm option. For additional information on the adaptive time step algorithm see Section 4.2.

Table 3-5 Summary of SNAP/RADTRAD inputs – Model Options

Input	Description
Model Options – General	
Title	Problem title (optional), specified by user. Typically, it is a good idea to name the problem particularly since multiple models can be accessed in a single SNAP Model Editor session.
Description	Problem description (optional), specified by user. Good idea to provide a short problem description for the record.
Plant Power Level	Core power level in MWt (required).
Decay	Select one of the following options: • *Decay and daughtering* • *No decay or daughtering* • *Decay, no daughtering* (default).
Onset of Gap Release	Specify the time that the gap release from the fuel starts in hours (required). The default is 0.0 hours which is recommended for most SNAP/RADTRAD models.
Start of Accident	Specify the time that the accident starts in hours (required). This parameter is **only** significant if radionuclide decay is being calculated. The default is 0.0 hours which is recommended for most SNAP/RADTRAD models.

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Input	Description
Accident Duration	Specify the time the accident ends in hours (required). The default is 720 hours which is recommended for most SNAP/RADTRAD models.
Dose Conversion Type	Select one of the following options for DCFs: • *User defined* • *FGR 11 & 12* (default) Generally, the default FGR 11&12 DCFs should be used.
Dose Conversions	Values for FGR 11 & 12 can be displayed. If user-defined is selected, then user can input DCFs.
Time Step Algorithm	Two algorithms are available for controlling the time step: • *Default* • *Adaptive* • *Default with Error Calculation* The default time step algorithm is the original RADTRAD (version 3.10) algorithm implemented with the ASH solver. The adaptive time step algorithm was introduced with the RADTRAD-AC (version 4.5) and is discussed in Section 4.2.
Time Step Table	Specified by user. This option allows the user to specify time steps for finer time step resolution for the default time step algorithm and also used to control the generation of output. Normally, SNAP/RADTRAD generates time-dependent output at each time point where there is a change in the time-dependent input data such as X/Q, filtration efficiency, etc.
Model Options – Output Parameters	
The following output parameter flags only affect the *casename.out* output file.	
Echo Model Definition	The flag options are either *True* or *False* and specified by the user. If set to false, the edited summary of the input is suppressed.
Show Event	The flag options are either *True* or *False* and specified by the user. User should set this flag to true to get the output for all time steps
Show Step	The flag options are either *True* or *False* and specified by the user.
Show Model	The flag options are either *True* or *False* and specified by the user.
Iodine Units	User selects from the following options: • *switch to compare with original result*s • *version 1.0 – 3.03 behavior* (default) • *only Curies edited (version 3.10)* The default 3.03 behavior generates output similar to RADTRAD 3.03. In general, the version 3.10 output is more useful to the dose analyst.

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Input	Description
Model Options – NRC Output Flags	
The available flags that control the generation of output to the NRC-formatted output file. Note that the bulk of the output is generated for the Delta Dose and Cumulative Dose results.	
Input Echo	The flag options are either *True* or *False* and the default value is set to *True*.
General Input Parameters	The flag options are either *True* or *False* and the default value is set to *True*.
Source Term Parameters	The flag options are either *True* or *False* and the default value is set to *True*.
Dose Conversion Factor Data	The flag options are either *True* or *False* and the default value is set to *True*.
Compartment Data	The flag options are either *True* or *False* and the default value is set to *True*.
Flow Path Data	The flag options are either *True* or *False* and the default value is set to *True*.
Dose Location Data	The flag options are either *True* or *False* and the default value is set to *True*.
Activity Distribution Results	The flag options are either *True* or *False* and the default value is set to *True*.
Delta Dose Results	The flag options are either *True* or *False* and the default value is set to *True*.
Cumulative Dose Results	The flag options are either *True* or *False* and the default value is set to *True*.
I-131 Activity Summary	The flag options are either *True* or *False* and the default value is set to *True*.
Flow Path Summary	The flag options are either *True* or *False* and the default value is set to *True*.
Model Options – Diagnostic Flags	
Level – xxx	Flags for generating additional output for code debugging. Not generally used for SNAP/RADTRAD analyses.

3.4.2 Nuclear Data and Source Scenarios

The source term specification was introduced in Section 3.3.4. However, a new feature that has been added to SNAP/RADTRAD is the ability to consider the reactor coolant system (RCS)

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activity for either a PWR or BWR. The user can access the *RCS Activity Calculator* window, Figure 3-47, by clicking on the *Open RCS Activity Calculator* ( ) icon on the *Edit Total Inventories* window shown in Figure 3-33. The user has the option to enter RCS activity or use the SNAP/RADTRAD to calculate the activity. Formulations for the calculation of RCS activity are presented in Section 4.4. Figure 3-47 displays the *RCS Activity Calculator* window where the user can select from either BWR or PWR. Tables 3-6 and 3-7 list the available inputs for the *Nuclear Data* and *Source* nodes in SNAP/RADTRAD.

The user will note that the *RCS Activity Calculator* window in Figure 3-47 is an input specification window where parameters need to be specified to determine the RCS activity. There are two options are available for the user to calculate RCS activity.

1. The user can input the RCS specific activity (*μCi/g*) in the *Activity* column (Figure 3-47 and then add the effect of iodine spiking by checking either the *Use pre-incident spike* or the *Use co-incident spike* box. If the user checks the *Use co-incident spike* box, then the *Calculate Appearance* button on Figure 3-47 will become active. Note that the co-incident spike model is not applicable to BWRs.
2. The user can also have SNAP/RADTRAD calculate the activity and add the effect of a pre-incident or co-incident spike to the total RCS activity.

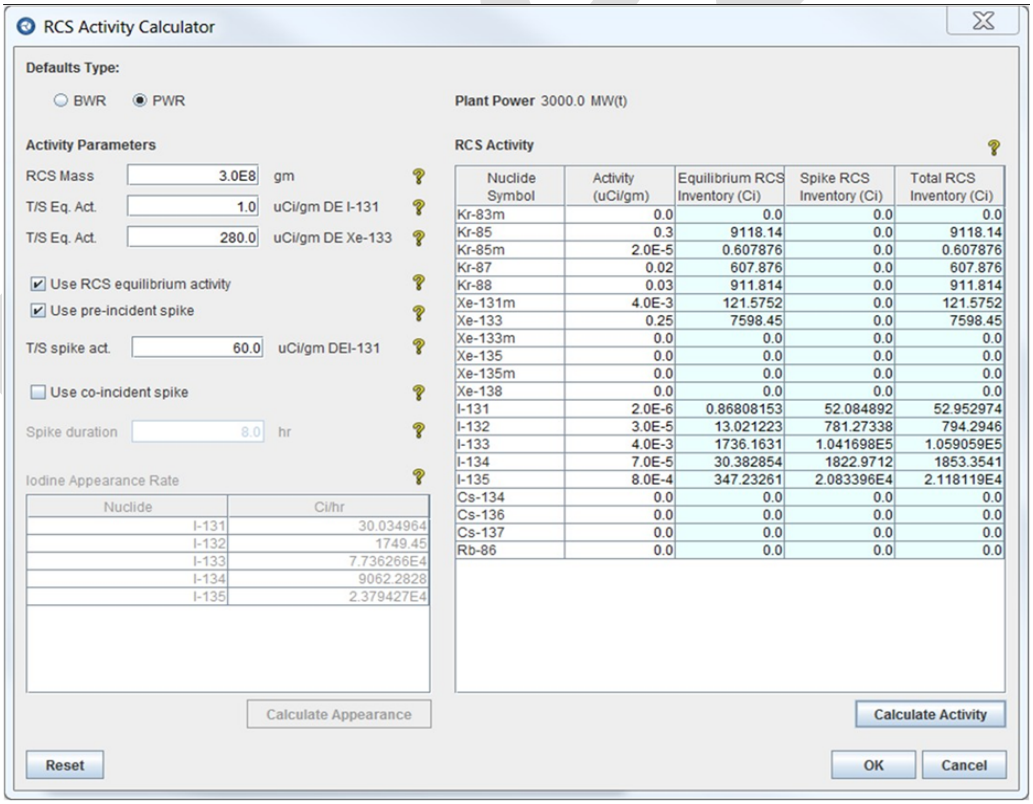

Figure 3-47 RCS activity calculator window

In Figure 3-47, the user will note the *Activity* column is editable so that the user can input the known specific activity and the RCS mass in grams and the RCS inventory will be calculated. Generally, RCS specific activities are presented in Chapter 11 of the Final Safety Evaluation Report for a given plant. Once the specific activity is entered, the user has the option to calculate the iodine and xenon equilibrium activities from the specified equilibrium activity for the dose equivalent iodine 131 (DE I-131) or the dose equivalent xenon 133 (DE Xe-133) from the facility's technical specification (T/S) equilibrium specific activity. These calculations are done by checking or unchecking the appropriate boxes on the *RCS Activity Calculator* window. Note that the calculations are completed using the user-specified specific activity (μCi/g).

Additionally, after selecting either the *BWR* or the *PWR* option on Figure 3-47, when the user selects the *Calculate Activity* button on Figure 3-47 either Figure 3-48 or 3-49 will open respectively. In either instance, the user fills in the required data and clicks on *OK* button to complete the calculation. Note that for the BWR, the user can apply the calculation to either steam or liquid by clicking on either the *Steam activity* or *Liquid activity* option shown in Figure 3-49.

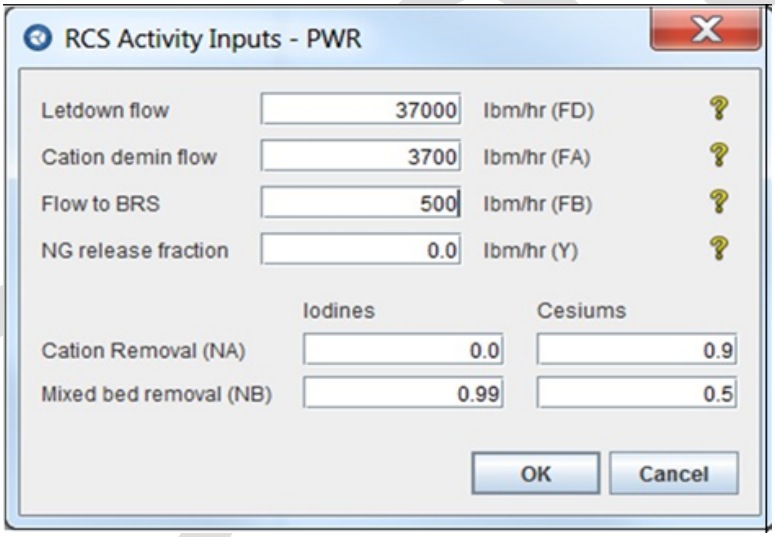

Figure 3-48 RCS Activity Inputs – PWR window

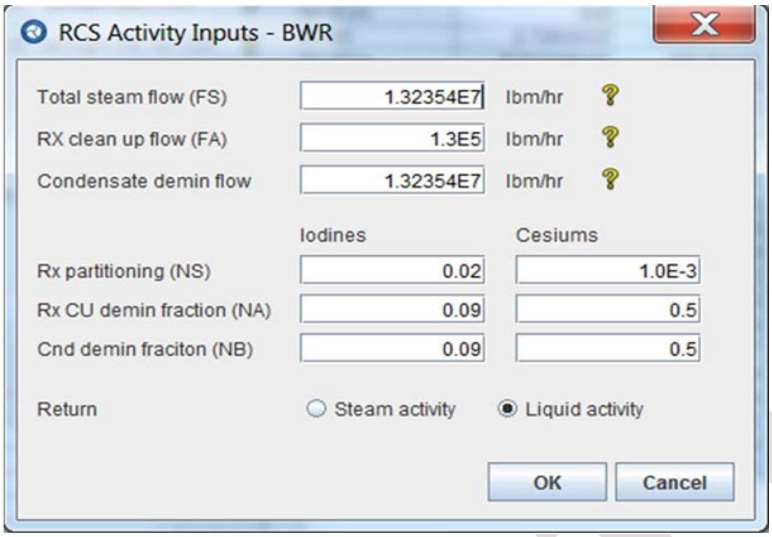

Figure 3-49 RCS Activity Inputs – BWR window

To apply pre-incident or co-incident spiking to either user-supplied or code-calculated RCS specific activities, the appropriate box is checked on the *RCS Activity Calculator* window (Figure 3-47) and the required input supplied. For the pre-incident spike, which is applicable to either PWRs or BWRs, the user checks the *Use pre-incident spike* box and supplies the T/S spike activity.

To use the co-incident spike, which is applicable only to PWRs, the user can either fill out the table in the *Iodine Appearance Rate* section (Figure 3-47) to specify the iodine appearance rate or choose the *Calculate Appearance* button. Note that the iodine appearance rate *Ci/hr* column is editable so that the user can enter appropriate values of the iodine appearance rate. If the user chooses to have SNAP/RADTRAD calculate the iodine appearance rate values, then select the *Calculate Appearance* button on the *Iodine Appearance Rate* section (Figure 3-47). When the user clicks the *Calculate Appearance* button the *Calculate Iodine Appearance* input window as shown in Figure 3-50 will open. The user will provide the required inputs and click the *OK* button which will update the iodine appearance rate values in the table in the *Iodine Appearance Rate* section of Figure 3-47.

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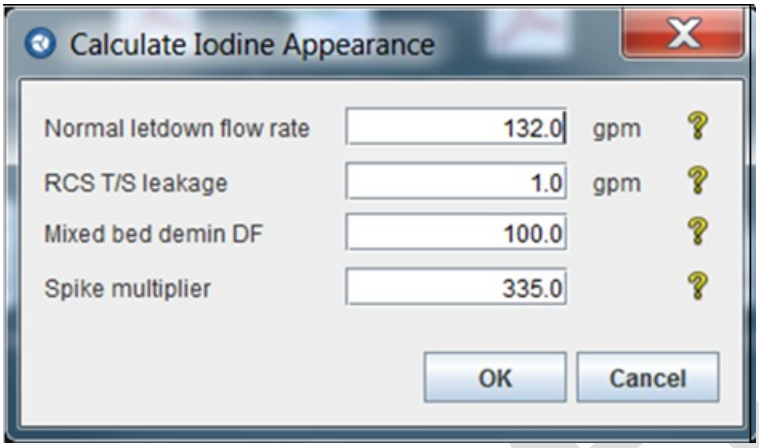

Figure 3-50 Calculate Iodine Activity window

Once the RCS activity calculations are complete, the user clicks on the OK button on the *RCS Activity Calculator* window (Figure 3-47) and the total RCS activity is transferred from the RCS activity calculator to the *Inventory (Ci)* column in the *Edit Total Inventories* window (Figure 3-33) and the specific inventory amount is back-calculated from the core power. Note that a new file is created each time the RCS activity calculator is invoked. These files are automatically named, but the user can rename them from the *Name* text box in the *Edit Total Inventories* window (Figure 3-33). Finally the models used to compute the RCS activity are discussed in Section 4.4.

Regardless of whether fuel or RCS activity is used, it is the total inventory that is the basis for the source term calculation accessed from the *Source Scenarios* text box, in the *Property* window, once a new source model is initiated. Recall from earlier discussions that part of the specification of a new source scenario is the appropriate nuclide inventory either from the reactor fuel, RCS or other source. Once that step is completed, an appropriate release model is specified from the available pre-defined release models are listed under the *Accident Parameters* tab on the *Edit Inventory Scenario* window as shown in Figure 3-51. Note that the initial inventory prior to the application of release fractions appears under the *Adjusted Inventory* tab while the *Source Term* tab lists the actual releases to be used in the model after multiplication by the release fractions.

- For the *Use Total Inventory* option, user-defined release data are specified under the *Release Fractions and Timings* tab.
- For *DBA-TID* and *DBA-AST* options, the release fractions are also listed under the *Release Fractions and Timings* tab. The basis for the values for these options is presented in Section 4.2.
- For the *Gap Release*, rod ejection accidents-control rod drop accidents (*REA-CRDA*), and fuel handling accidents (*FHA*) options, the default release fractions are set under the

Accident Parameters tab as each accident is selected. The release fractions for the relevant nuclide groups are set to 1 under the *Release Fractions and Timings* tab.

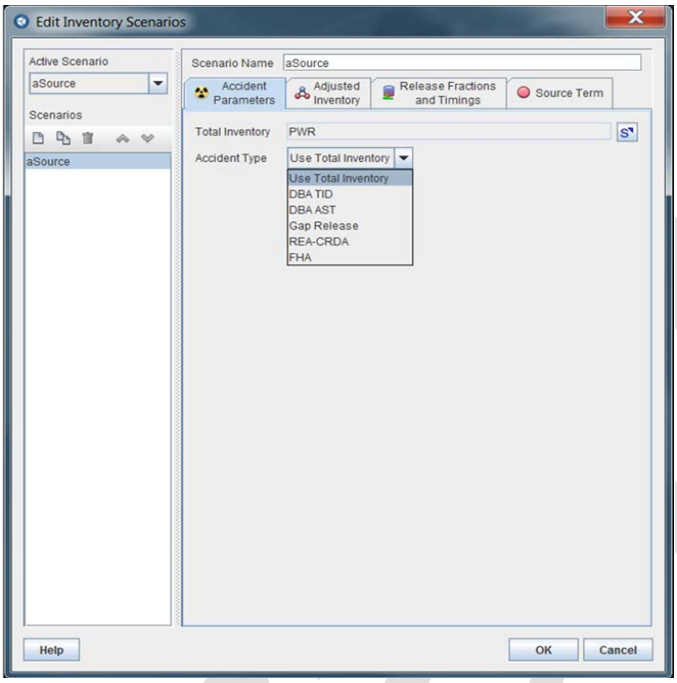

Figure 3-51 Available pre-defined SNAP/RADTRAD release models

Table 3-6 Summary of SNAP/RADTRAD inputs – Nuclear Data

Input	Description
Nuclide Model	Select one of the following options: • *ICRP-38 definitions* (default) • *User Defined* It is recommended that the ICRP-38 data be used.
Nuclides	Specified by user when the *User Defined* option chosen. Note that the nuclide definitions can be reviewed by selecting *Custom Editors* ( ) icon. This will open the *Nuclide Definitions* window, which contains the *nuclide name*, *atomic mass* and *half-life* on the left-hand side. When a user clicks on a nuclide on the left-hand side the daughter nuclides and its associated branching ratios will be displayed on the right-hand side of the window.
Total Inventories	Used to develop radionuclide inventories in the fuel or in the RCS. This input works in conjunction with the *Sources* node to develop a source term. The two default core inventories for a PWR and BWR from RADTRAD 3.03 are included in the SNAP Model Editor. Core inventories can also be specified by the user.

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Table 3-7 Summary of SNAP/RADTRAD inputs – Sources

Input	Description
Name	Specified by user (optional).
Component Number	Multiple sources can be used in a model and the SNAP/RADTRAD Model Editor assigns the number.
Description	Specified by user (optional).
Source Scenarios	Various source (release) scenarios are available to the users which are linked to the *Nuclide Data* definition. Source scenarios include LOCA DBAs and non-LOCA DBAs such as FHA, CRDA or REA, and Gap releases. Additionally, scenarios involving RCS activity, such as steam generator tube ruptures and main steam line breaks can also be defined.
Source Term Fractions	User defined value which is the fraction of the inventory being released by the source. Multiple sources referencing the same inventory can divide the source term between them through this value.
Iodine Physical Form	Specified the fraction of iodine that is in elemental, organic or particulate chemical form. Predefined fractions are listed below and are user-selectable from the dropdown menu. • *TID-14844* – 0.05 aerosol (particulate), 0.91 (elemental), and 0.04 (organic) • *NUREG–1465* – 0.95 aerosol (particulate), 0.0485 (elemental), and 1.5E-3 (organic). • *User Defined* Note that if one of the predefined fraction options is selected, the above fractions appear in the *Aerosol Fraction*, *Elemental Fraction* or *Organic Fraction* text boxes. These fields are greyed-out and are not editable. Selecting the user-defined option from the iodine physical form dropdown menu allows the user to specify the aerosol, elemental, and organic fractions.
Compartments	Links the release scenario to a given compartment. Works in conjunction with the compartment specification.

3.4.3 Compartments, Pathways, Natural Deposition, Filters and Sprays

Section 3.3.2 presented the approach for defining compartments and pathways and connecting these two components. Once an initial model is developed, completing the model is a matter of input specification. Input specification is done by specifying input in text boxes, selecting options in drop-down menus or buttons or through data entry tables for time-dependent data. Tables 3-8 through 3-12 list the available inputs for the *Compartments*, Pathways, Natural Deposition, Filters and Spray nodes in SNAP/RADTRAD.

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Table 3-8 Summary of SNAP/RADTRAD inputs – Compartments

Input	Description
Name	Specified by user (optional).
Component Number	Multiple compartments can be used in a model and the SNAP/RADTRAD Model Editor assigns the number.
Description	Specified by user (optional).
Type	The user can select from the following options: • *Unused* • *Control Room Dose* • *Environment* • *Normal* • *Normal Dose* • *Control Room* Each model must have exactly one environment and control rooms do not exhaust to other compartments. Additionally, *Normal* may be used for any compartment that is neither the *Environment* nor a *Control Room*. Note that an *Environment* compartment is defined by default in SNAP/RADTRAD. Additional compartments are specified by the user.
Output Level Detail	Sets the detail level used to output compartment data during model execution. The user can select from the following options: • *No additional detail* • *Full edit at time steps* • *Full edit at end of problem only*. When set to *Full edit at time steps*, the editing of nuclide activity and decontamination for the compartment are printed to the output. These details may be printed at every time step or only once, at the end of the problem.
Volume	Specified by user (ft^3 or m^3 depending on user-specified units selection).
Deposition	Works in conjunction with the *Natural Deposition* node summarized in Table 3-10. Used in *Normal* and *Normal Dose* compartments as appropriate.
Filter	Works in conjunction with the *Filter* node summarized in Table 3-11. Used in *Normal* and *Normal Dose* compartments as appropriate.
Spray	Works in conjunction with the *Spray* node summarized in Table 3-12. Used in *Normal* and *Normal Dose* compartments as appropriate.

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Table 3-9 Summary of SNAP/RADTRAD inputs – Pathways

Input	Description
Name	Specified by user (optional).
Component Number	Multiple pathways can be used in a model and the SNAP/RADTRAD Model Editor assigns the number.
Description	Specified by user (optional).
From Compartment	Lists the upstream connecting compartment when connections are made between components.
To Compartment	Lists the downstream connecting compartment when connections are made between components.
Pathway Type	The method by which radionuclides are transported and deposited through the pathway. The user can select from the following options: • *Piping* – transport in volumetric flow with a decontamination factor. • *Filtered pathway* – transport in volumetric flow through filters with a specified efficiency. • *Generic* – transport in volumetric flow with a decontamination factor (replaces legacy suppression pool mechanism). Allows for the user to independently specify the decontamination for aerosols (particulate), elemental iodine, organic iodine, and noble gases. • *Air leakage* – transport in volumetric percent (%/day). This is the typical path used for containment leakage. • *Generic w/non-Iodine aerosols* – transport is the same as the Generic option above without Iodine particulate.
Printout Level Detail	Determines how additional pathway details are written to the output file. The user can select from the following options: • *None* – writes no extra details. • *Transport Each Time Step* – writes information about the transport for each group (noble gas, elemental, organic, and aerosol (particulate)) at each time step. • *Nuclide and Transport Each Time Step* – same as the option above, but includes information about each transported nuclide. • *Nuclide and Transport at End Only* – same as the option above, but only written out at the end of the calculation.

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Input	Description
Aerosol Removal Model (if pathway type is Piping)	Specifies how aerosols (particulates) are deposited in the pipe. The user can select from the following options: • *No aerosol removal* – the pipe does not decontaminate particulate iodine transport. • *User Defined Decontamination Factors* – if the user selects this option the *Aerosol DF* text box appears below this option. Select the *Custom Editors* (E) icon for this text box to open the *Editing Aerosol DF* window. The user enters time-dependent decontamination factors and flow rates (ft^3/min or m^3/s) in the data entry table. • *Brockmann-Bixler Model* – If the user selects this option the following additional input text boxes appear below this option with user-specified values to be entered: ▪ *pipe volume* (ft^3 or m^3) ▪ *pipe surface area* (ft^2 or m^2) ▪ *pipe angle* (degrees) ▪ *pipe temperature* (°F or °C) ▪ *pipe pressure* (psi or kPa) ▪ *pipe aerosol settling velocity* (ft/min or m/s) ▪ *pipe aerosol flow rates* are entered by selecting the *Custom Editors* (E) icon to open the *Editing Pipe Aerosol Flow Rates* window. Enter the flow rates (ft/min or m/s) as a function of time in the data entry table.
Elemental Iodine Removal Model (if pathway type is Piping)	Determines how elemental iodine is deposited in the pipe. The user can select from the following options: • *No aerosol removal* – the pipe does not decontaminate elemental iodine transport. • *Enter DFs and Flow Rates* – if the user selects this option the transport is defined as a function of flow rate and DFs over time. When this option is selected the *Elemental Iodine DF* text box appears below this option. Select the *Custom Editors* (E) icon for this text box to open the *Editing Elemental Iodine DF* window. The user enters time-dependent decontamination factors and flow rates (ft^3/min or m^3/s) in the data entry table. • *Enter Deposition Velocity* – If the user selects this option the *Elemental Iodine Deposition Velocity* text box appears below this option. The user enters iodine the deposition velocity (ft/min or m/s).

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Input	Description
Organic Iodine Removal Model (if pathway type is Piping)	Determines how organic iodine is deposited in the pipe. The user can select from the following options: • *No aerosol removal* – the pipe does not decontaminate organic iodine transport. • *Enter DFs and Flow Rates* – if the user selects this option the transport is defined as a function of flow rate and DFs over time. When this option is selected the *Organic Iodine DF* text box appears below this option. Select the *Custom Editors* ( ) icon for this text box to open the *Editing Organic Iodine DF* window. The user enters time-dependent decontamination factors and flow rates (ft^3/min or m^3/s) in the data entry table. • *Enter Deposition Velocity* – If the user selects this option the *Organic Iodine Deposition Velocity* text box appears below this option. The user enters iodine the deposition velocity (ft/min or m/s).
Filter (if pathway type is Filter Pathway)	Specifies the air filter removing radionuclides from transport in the pathway. Use the *Select* ( ) icon to open the *Select from Filters* window to link to one of the available filter models or creates a filter component.
Aerosol DF (if pathway type is Generic or Generic w/non-Iodine Aerosols)	Select the *Custom Editors* ( ) icon for this text box to open the *Editing Aerosol DF* window. Enter the time-dependent DFs and flow rates (ft^3/min or m^3/s) in the data entry table.
Elemental Iodine DF (if pathway type is Generic or Generic w/non-Iodine Aerosols)	Select the *Custom Editors* ( ) icon for this text box to open the *Editing Elemental Iodine DF* window. Enter the time-dependent DFs and flow rates (ft^3/min or m^3/s) in the data entry table.
Organic Iodine DF (if pathway type is Generic or Generic w/non-Iodine Aerosols)	Select the *Custom Editors* ( ) icon for this text box to open the *Editing Organic Iodine DF* window. Enter the time-dependent DFs and flow rates (ft^3/min or m^3/s) in the data entry table.
Noble Gas Flow Rates (if pathway type is Generic or Generic w/non-Iodine Aerosols)	Select the *Custom Editors* ( ) icon for this text box to open the *Editing Noble Gas Flow Rates* window. Enter the time-dependent flow rates (ft^3/min or m^3/s) in the data entry table.
Leakage Rate (if pathway type is Air leakage)	Select the *Custom Editors* ( ) icon for this text box to open the *Editing Leakage Rate* window. Enter the time-dependent flow leakage rates (%/day) in the data entry table.

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Table 3-10 Summary of SNAP/RADTRAD inputs – Natural Deposition

Input	Description
Name	Specified by user (optional).
Component Number	Multiple natural deposition models can be used in a model and the SNAP/RADTRAD Model Editor assigns the number.
Description	Specified by user (optional).
Aerosol Deposition Model	Specifies the method by which the deposition removes radionuclides from the compartment. The user can select from the following options: • *None* – the deposition provides no decontamination. • *User Defined Coefficients* – decontamination is specified as a function of removal coefficients over time. • *Henry's Model Coefficients* – the Henry's correlation model for natural deposition, specified as a function of height and particle density over time. • *Powers' Deposition Model* – the Powers' model for natural deposition, calculated based on an uncertainty percentile associated with a reactor and accident type. This model is reasonable only for large buildings, and is not valid for deposition in passages such as pipes.
Aerosol Removal Coefficients (if Aerosol Deposition Model is User Defined Coefficients)	Defines the aerosol (particulate) radionuclide removal as a function of time. The removal coefficient is defined as the fraction of the total aerosol mass inserted into the containment removed per second. Select the *Custom Editors* ( ) icon for this text box to open the *Editing Aerosol Removal Coefficients* window. Enter the time-dependent removal coefficients (1/hour) in the data entry table.
Henry Deposition Table Data (if Aerosol Deposition Model is Henry Model Coefficients)	The natural deposition as a function of compartment height and particle density over time. The table is used by the code to determine an appropriate amount of decontamination. Select the *Custom Editors* ( ) icon for this text box to open the *Editing Henry's Deposition Table Data* window. Enter the time-dependent height (ft or m) and particle density (lb/ft^3 or g/cm^3) in the data entry table.
Powers Accident Model Type (if Aerosol Deposition Model is Powers Deposition Model)	Sets the model of decontamination based on the type of reactor and accident. Select the accident type using the dropdown menu. • *PWR-DBA* • *PWR-SA* • *BWR-DBA* • *BWR-SA* • *APWR-DBA*

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Input	Description
Power's Model Percentile (if Aerosol Deposition Model is Powers Deposition Model)	Sets the uncertainty percentile for the Powers model of natural deposition. Select the accident type using the dropdown menu. • *10%* • *50%* • *90%*
Elemental Deposition Model Type	Determines the method by which the deposition removes elemental iodine from the compartment. The user can select from the following options: • *None* – the deposition provides no decontamination. • *User Defined Coefficients* – decontamination is specified as a function of removal coefficients over time. When this option is selected the *Elemental Iodine Removal Coefficient* text box appears below this option. Select the *Custom Editors* ( ) icon for this text box to open the *Editing Elemental Iodine Removal Coefficient* window. The user enters time-dependent elemental iodine removal coefficients (1/hour) in the data entry table.

Table 3-11 Summary of SNAP/RADTRAD inputs – Filters

Input	Description
Name	Specified by user (optional).
Component Number	Multiple filters can be used in a model and the SNAP/RADTRAD Model Editor assigns the number.
Description	Specified by user (optional).
Filter Table	The recirculation filters definition as a function of time. Select the *Custom Editors* ( ) icon for this text box to open the *Editing Filter Table* window. Each row defines time dependent filter flows (ft^3/min or m^3/s) and efficiencies (%) for: • *aerosol (particulate)* • *elemental iodine* • *organic iodine filtration* There is no noble gas efficiency as it is assumed that the noble gas group cannot be captured. The efficiencies will change in a stepwise fashion at each specified time.

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Table 3-12 Summary of SNAP/RADTRAD inputs – Sprays

Input	Description
Name	Specified by user (optional).
Component Number	Multiple spray models can be used in a model and the SNAP/RADTRAD Model Editor assigns the number.
Description	Specified by user (optional).
Aerosol Removal Model	Determines the method by which the spray removes aerosol (particulate) radionuclides from the compartment. The user can select from the following options: • *None* – aerosols are not removed from the comp. • *User Defined Coefficient Table* – aerosols are removed as an aerosol removal coefficient over time. When this option is selected the *Aerosol Removal Coefficients*, *Aerosol DF Limit Enabled*, *Aerosol DF Limit*, *Aerosol Lambda/10 DF Limit Enabled*, and the *Aerosol Lambda/10 DF Limit* text boxes appear below this option. • *Powers' Model* – aerosols are removed by the Powers and Burson model, which takes into account sprayed and non-sprayed volume, deposition percentile, and spray flux ratio and height over time.
Aerosol Removal Coefficients (if Aerosol Removal Model type is User Defined Coefficient Table)	Select the *Custom Editors* (E) icon for this text box to open the *Editing Aerosol Removal Coefficients* window. The user enters time-dependent aerosol removal coefficients (1/hour) in the data entry table.
Aerosol DF Limit Enabled (if Aerosol Removal Model is User Defined Coefficient Table)	The user selects from either *True* or *False* to enable the DF beyond which the ability of the spray to remove aerosols drops in effectiveness.
Aerosol DF Limit (if Aerosol Removal Model is User Defined Coefficient Table)	The DF beyond which the ability of the spray to remove aerosols drops in effectiveness. The DF value must be 1.0 or greater and the default value is 1.0E+06.
Aerosol DF Limit, Aerosol Lambda/10 DF Limit Enabled (if Aerosol Removal Model is User Defined Coefficient Table)	The user selects from either *True* or *False* to enable the DF beyond which the sprays effectiveness is reduced by a factor of 10.
Aerosol Lambda/10 DF Limit (if Aerosol Removal Model is the Powers Model)	The DF beyond which the sprays effectiveness is reduced by a factor of 10. The DF value must be 1.0 or greater and the default value is 1.0E+06.

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Input	Description
Powers Model Spray Table (if Aerosol Removal Model is the Powers Model)	A function of spray flux and height of the spray above the main floor. Select the *Custom Editors* (E) icon for this text box to open the *Editing Powers Model Spray Table* window. Enter the time-dependent spray flux (cfm/ft^2 or (m^3/s)/m^2) and spray height (ft or m). The spray flux is defined as the total spray flow divided by the floor area of the compartment. The compartment floor area is approximately the compartment open volume divided by the compartment height. The Powers' model is only valid for spray flux ratios between 0.002 and 0.5 cfm/ft^2 (1.016E-05 to 2.54E-03 (m^3/s)/m^2) and spray fall heights between 16.4 and 165 feet (5 to 50.29 meters).
Powers Model Spray Ratio (if Aerosol Removal Model is the Powers Model)	The ratio of unsprayed to sprayed volume in the compartment. This is typically zero, as the unsprayed volume is often modeled as a separate compartment. Good mixing is assumed for any ratio above zero; if good mixing is not available, the sprayed and unsprayed compartments should be modeled separately.
Powers Model Percentile (if Aerosol Removal Model is the Powers Model)	The percentile model used in the calculation. Select the percent using the dropdown menu. • *10%* • *50%* • *90%*
Elemental Iodine Removal Model	Determines the method by which the spray removes aerosol (particulate) radionuclides from the compartment. The user can select from the following options: • *None* – aerosols are not removed from the comp. • *User Defined Coefficient Table* – aerosols are removed as an aerosol removal coefficient over time. When this option is selected the *Aerosol Removal Coefficients*, *Aerosol DF Limit Enabled*, *Aerosol DF Limit*, *Aerosol Lambda/10 DF Limit Enabled*, and the *Aerosol Lambda/10 DF Limit* text boxes appear below this option.
Elemental Iodine Removal Coefficients (if Elemental Iodine Removal Model is the User Defined Coefficients)	Defines the elemental iodine radionuclide removal as a function of time. Select the *Custom Editors* (E) icon for this text box to open the *Editing Elemental Iodine Removal Coefficients* window. The user enters time-dependent elemental iodine removal coefficients (1/hour) in the data entry table.
Elemental-I DF Limit Enabled (if Elemental Iodine Removal Model is the User Defined Coefficients)	The user selects from either *True* or *False* to enable the DF beyond which the ability of the spray to remove elemental iodine drops in effectiveness.

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Input	Description
Elemental-I DF Limit (if Elemental Iodine Removal Model is the User Defined Coefficients)	The DF beyond which the sprays effectiveness to remove elemental iodine is reduced by a factor of 10. The DF value must be 1.0 or greater and the default value is 1.0E+06.
Organic Iodine Removal Model	Determines the method by which the spray removes organic iodine from the compartment. The user can select from the following options: • *None* – organic radionuclides are not removed from the compartment. • *User Defined Coefficient Table* – organic radionuclides are removed as an organic removal coefficient over time.
Organic Iodine Removal Coefficients (if Organic Iodine Removal Model is the User Defined Coefficients)	Defines the organic iodine radionuclide removal as a function of time. Select the *Custom Editors* (E) icon for this text box to open the *Editing Organic Iodine Removal Coefficients* window. The user enters time-dependent elemental iodine removal coefficients (1/hour) in the data entry table.

3.4.4 Dose Locations, Breathing Rates, and X/Q Tables

Section 3.3.3 presented the approach for defining dose locations, breathing rates, and X/Q tables. Generally, the default breathing rates are used for most analyses and are entered under the *Dose Locations* node in the *Property* window. The values for X/Q are specified through the use of data entry tables as illustrated in Section 3.3.3. Tables 3-13 and 3-14 list the available inputs for the *Dose Locations* and *X/Q Tables* nodes in SNAP/RADTRAD.

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Table 3-13 Summary of SNAP/RADTRAD inputs – Dose Locations

<table>
<tr><th>Input</th><th>Description</th></tr>
<tr><td>Name</td><td>The EAB or LPZ dose location names are set by SNAP/RADTRAD.</td></tr>
<tr><td>Description</td><td>The EAB or LPZ dose location descriptions are set by SNAP/RADTRAD.</td></tr>
<tr><td>Component Number</td><td>Multiple dose locations can be used in a model and the SNAP/RADTRAD Model Editor assigns the number.</td></tr>
<tr><td>Breathing Rates</td><td>Defines the breathing rates at the dose locations as a function of time. Select the Custom Editors (E) icon for this text box to open the Editing Breathing Rates window. The user can then use the default breathing rates by selecting the Default button and choosing between either the EAB/LPZ or Control Room options. The default breathing rates for each are listed below:
EAB/LPZ
<table>
<tr><th>Time (h)</th><th>Breathing Rates (m^3/s)</th></tr>
<tr><td>0.0</td><td>3.5E-04</td></tr>
<tr><td>8.0</td><td>1.8E-04</td></tr>
<tr><td>24.0</td><td>2.3E-04</td></tr>
</table>
Control Room
<table>
<tr><th>Time (h)</th><th>Breathing Rates (m^3/s)</th></tr>
<tr><td>0.0</td><td>3.5E-04</td></tr>
</table>
Additionally the user can enter time-dependent breathing rates (ft^3/min or m^3/s) elemental iodine removal coefficients (1/hour) in the data entry table.</td></tr>
<tr><td>X/Q Table</td><td>Specifies the X/Q table to be used with this dose location. Use the Select (S) icon to open the Select from X/Q Tables window to link to one of the available X/Q tables.</td></tr>
<tr><td>Occupancy Factors</td><td>Specifies the occupancy factors table to be used with the control room (or the technical support center) dose location. Use the Custom Editors (E) icon to open the Editing Occupancy Factors window. The user can then use the provide time dependent occupancy factors for the dose location.</td></tr>
<tr><td>Compartment</td><td>Select the Custom Editors (E) icon for this text box to open the Select from Compartments window. EAB and LPZ dose locations set to the Environment compartment by default.</td></tr>
</table>

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Table 3-14 Summary of SNAP/RADTRAD inputs – X/Q Tables

Input	Description
Name	X/Q nodes are specified for the EAB and LPZ dose locations by default in SNAP/RADTRAD. Users must specify X/Q data for the EAB and LPZ. X/Q data for additional dose locations can be specified by the user (optional).
Component Number	The EAB is set to component 1 and LPZ is set to component 2 by SNAP/RADTRAD. User-specified X/Q tables are automatically numbered by SNAP/RADTRAD.
Description	Specified by user (optional).
X/Q Table	Select the *Custom Editors* (E) icon for this text box to open the *Editing X/Q Tables* window. The user enters time-dependent X/Q values (s/m^3) in the data entry table.

One item of note is the link between the dose location and X/Q table. The link is activated from the environment compartment as shown in Figure 3-52. The user opens the Property window for the environment compartment and selects the *Custom Editors* (E) icon to the right of the *Onsite X/Q Tables* text box. The *Onsite X/Q Table Map* window will appear and the user can link the X/Q table and dose location. The remaining nodes under the Navigator window are listed and described in Table 3-15.

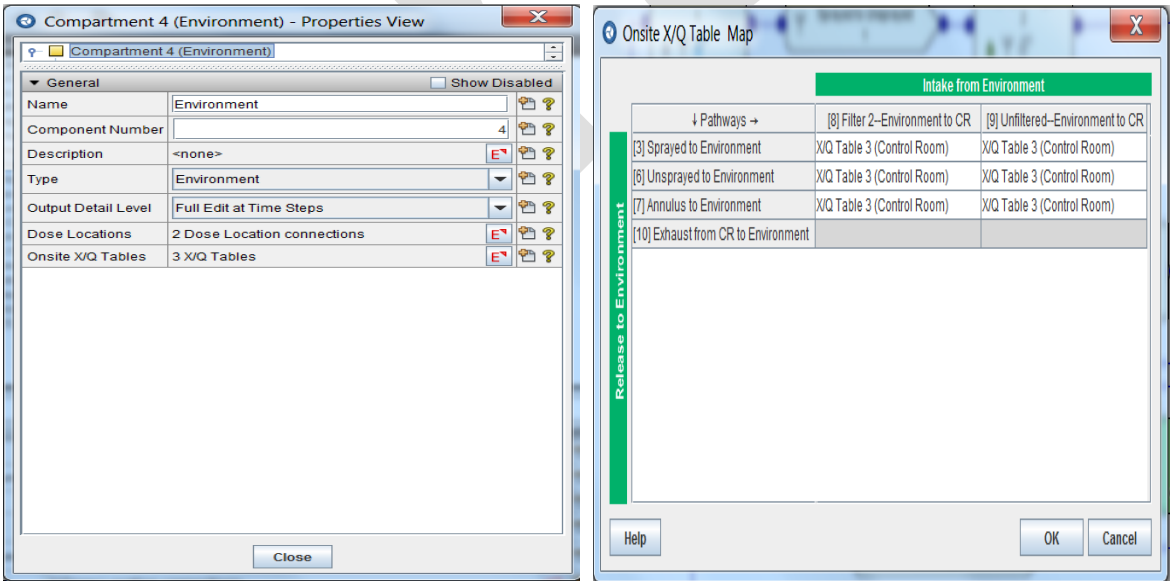

Figure 3-52 Linkage of a dose location and X/Q table for a compartment

Table 3-15 Summary of SNAP/RADTRAD inputs – Remaining Nodes

Input	Description
Connections	
Connections among compartments (paths), dose locations, and source connections can be specified. Usually, drag and drop is used. Note that connections between compartments cannot be created by the *Navigator* window. A pathway needs to be defined and then the connection needs to be made using the *Connection Tool* ( ) icon in the *View / Dock* window (see Section 3.3.2).	
Job Streams	
Name	The name for this job stream. This will be used to generate the relative path for the tasks that make up this stream. The default value for the name is *Simple_Stream* and it is recommended that SNAP/RADTRAD users change this to a unique name that is identifiable to the model (see Section 3.2.2).
Description	Specified by user (optional).
Stream Type	Defines the type of calculation that may be implemented through this job stream. The user can select from the following options: • *Basic Job Stream (default)* – a simple job stream. • *Numeric Combination* – builds a set of input models by modifying one or more shared numeric variables. Each selected shared numeric will either iterate through a list of predefined values or increment from a start value to an end value. • *Tabular Parametric* – the parametric case takes the form of a table of shared variable values. • *Dakota Uncertainty* – uncertainty support for the Dakota toolkit. SNAP/RADTRAD user should use the **default** value.
File Groups	Typically, the *File Groups* text box is **not used** in SNAP/RADTRAD. Defines groups of input sources and forces files inside file sets to be associated one-to-one with other file sets or parametric model node outputs.
Platform	The platform that this stream will be submitted to by default. The default value for SNAP/RADTRAD is *Local*.
Root Folder	The calculation server folder that this job stream will be executed in (see Section 3.2.2). Select the *Custom Editors* ( ) icon for this text box to open the *Edit Calculation Server Root Folders* window.
Relative Location	The relative location of this stream in relation to the selected staging location (see Section 3.2.2).
Log Level	Typically, the *Log Level* text box is not changed from the default value (*Information*) in SNAP/RADTRAD. Defines the current log level for messages produced by this stream.

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Input	Description
View in Job Status	This property determines whether the *SNAP Job Status* window will be opened to view the status of this stream after submission. The default value for SNAP/RADTRAD is *Yes*.
Linear Execution	Job Streams using Linear Execution are executed one task at a time, prioritized by their Step Number. In a normal (non-linear) Job Stream, tasks will be executed as soon as their dependencies are available (i.e. up-stream tasks are complete) up to the maximum number allowed by the platform. This option should only be used in situations where the stream must execute one task at a time and each task must complete before another can be executed. In most cases, including SNAP/RADTRAD, this value should be left at its default value (*No*).
Numerics	
The SNAP user-defined *Numerics* feature is designed to allow properties of a model to be modified and/or calculated outside the normal input for the model. Typically, the *Numerics* node is **not used** in SNAP/RADTRAD. To this end, a user may create real, integer, boolean, string, and table variables, as well and functions.	
Views	
The user can specify multiple views so that various model icons can be seen. Usually, one view (*Default View*) is sufficient for SNAP/RADTRAD models. The *Property* window for the *Default View* node values can be modified by the user as needed, but typically the default values for the text boxes will be sufficient for most models. Section 3.3.4 describes some of the options associated with the *Default View* node *Property* window text boxes. The user can select the Help (?) icon for each *Default View* node *Property* window text box to obtain more information on each one.	

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4.0 MODELS USED IN RADTRAD

The radiological consequences of an accident in a nuclear reactor depend upon the quantity of the radioactive material that escapes to the environment or enters into the control room. SNAP/RADTRAD is designed to calculate doses at offsite locations, such as the EAB, LPZ and in the control room. Source term models from TID-14844 [9] or from NUREG-1465 [10] are incorporated into SNAP/RADTRAD to describe fission product release from the fuel to the containment. Models for natural deposition within a compartment and engineered removal mechanisms, such as sprays and filters are available in the code. Flow between compartments is modeled and HEPA filters can be included in the flow paths for radionuclide removal due to filtration. Leakage to the environment can also be modeled and doses calculated to various points in the environment, such as the EAB and LPZ. After transporting the nuclides to different locations, SNAP/RADTRAD calculates the dose at user-specified locations. Note that much of the discussion in this section is based on the original RADTRAD documentation in NUREG/CR-6604 and its two supplements [1, 2 and 3].

4.1 Governing Equations in RADTRAD

The basic RADTRAD-AC model is a multi-compartment model where each compartment represents a portion of the plant being analyzed. Generally, the containment volume(s), environment, and control room(s) are modeled as compartments. Figure 4-1 presents a diagram illustrating a typical RADTRAD-AC model. Figure 4-1 shows a two-volume containment connected to the environment. A two-volume containment compartment may be used to represent the sprayed and unsprayed portions of the containment. A control room is shown which contains ventilation intakes from the environment through two filtered flow pathways, one recirculating and one that intakes directly from the environment. Recirculating filtered flow paths are typically used to reduce the airborne radionuclide concentration in the control room. The control room ventilation discharges back to the environment.

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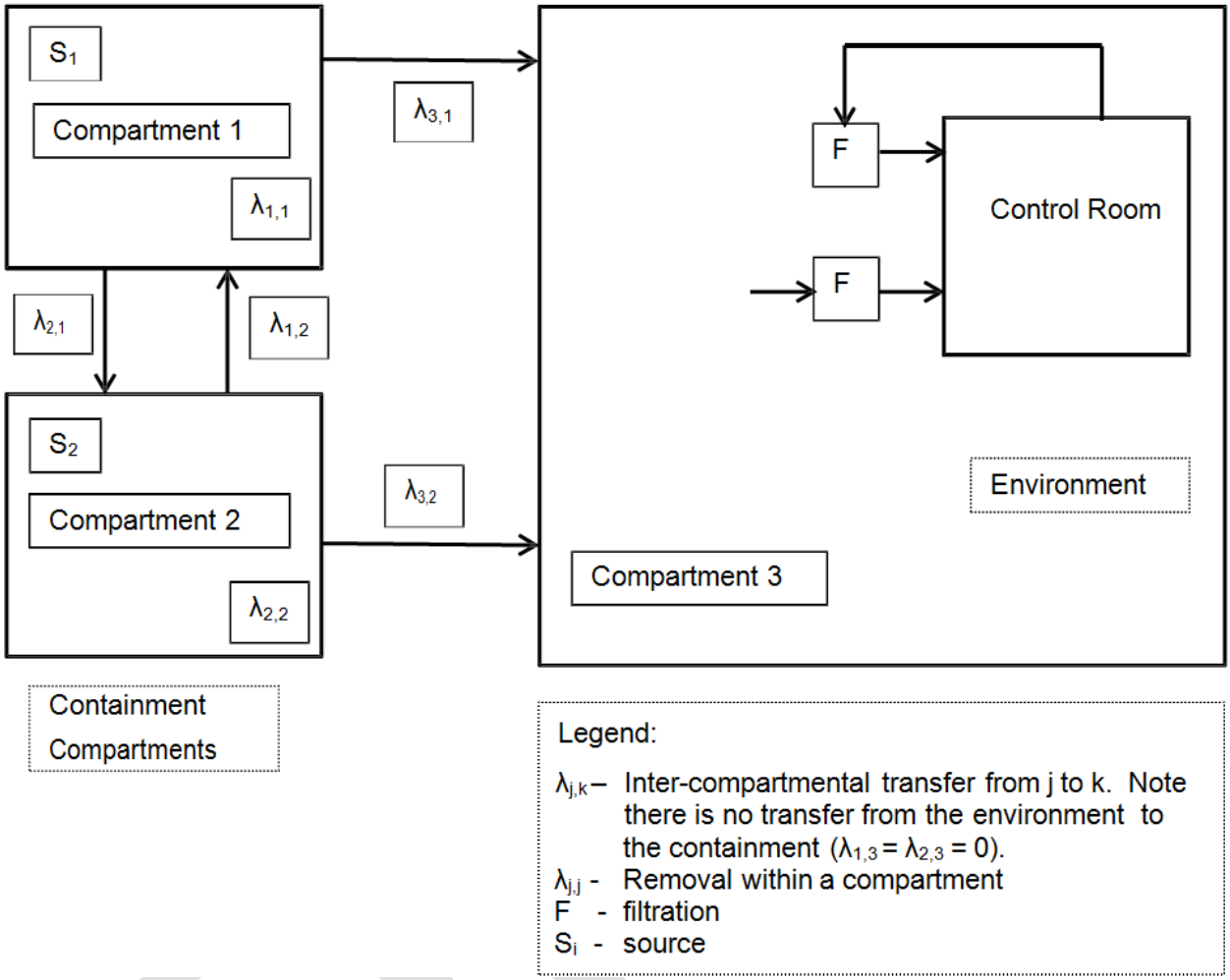

Figure 4-1 Schematic of a typical SNAP/RADTRAD dose assessment model

The governing equations in the RADTRAD-AC are basically balance equations relating the release of radionuclides typically from the reactor core to a given compartment to the removal of radionuclides within a given compartment and the transfer of radionuclides among compartments. Within each compartment except the environment, the radionuclides that are airborne within that compartment are assumed to be uniformly distributed or mixed. The environment compartment is where the EAB and LPZ dose points are located. Typically, the control room draws suction from the environment. Note that coupling of transfer pathways from the containment to the EAB, LPZ and control room intakes is done using X/Q values. The X/Q values relate the radionuclide concentration at a particular location to the radionuclide release rate due to atmospheric dilution. Since each X/Q value is associated with a release point and an intake location, the radionuclide inventory is not uniformly distributed in the environment compartment.

Removal of radionuclides within a compartment can be due to deposition, spray removal, decay and other processes. Compartments are connected by flow pathways which transfer radionuclides among compartments due to convection, forced flow, leakage or other transfer processes. Removal can also occur in a flow pathway due to filtration or deposition. Note that there are no removal processes in the environment compartment modeled in the RADTRAD-AC.

Referring to Figure 4-1, the radionuclide inventory in compartment 1 (upper left) is determined from Equation (4-1) for each species i

$$\frac{dN_1^i}{dt} = S_1^i - \lambda_{1,1}^i N_1^i + \lambda_{1,2}^i N_2^i + \lambda_{1,3}^i N_3^i \quad (4\text{-}1)$$

where

S_1^i = the release rate of species i in compartment 1 in atoms/s
$\lambda_{1,1}^i$ = the removal rate of species i within compartment 1 in 1/s
N_1^i = the inventory of species i in compartment 1 in atoms
$\lambda_{1,2}^i$ = the transfer rate of species i from compartment 2 to compartment 1 in 1/s
N_2^i = the inventory of species i in compartment 2 in atoms
$\lambda_{1,3}^i$ = the transfer rate of species i from compartment 3 to compartment 1 in 1/s
N_3^i = the inventory of species i in compartment 3 in atoms.

Note that in the RADTRAD-AC, radioactive material is tracked by elemental group rather than by radionuclide. For compartment 2, Equation (4-2) is used

$$\frac{dN_2^i}{dt} = S_2^i - \lambda_{2,2}^i N_2^i + \lambda_{2,1}^i N_1^i + \lambda_{2,3}^i N_3^i \quad (4\text{-}2)$$

where

S_2^i = the release rate of species i in compartment 2 in atoms/s
$\lambda_{2,2}^i$ = the removal rate of species i within compartment 2 in 1/s
N_1^i = the inventory of species i in compartment 1 in atoms
$\lambda_{2,1}^i$ = the transfer rate of species i from compartment 1 to compartment 2 in 1/s
N_2^i = the inventory of species i in compartment 2 in atoms
$\lambda_{2,3}^i$ = the transfer rate of species i from compartment 3 to compartment 2 in 1/s
N_3^i = the inventory of species i in compartment 3 in atoms.

Equations (4-1) and (4-2) can be generalized to any compartment (j). Equation (4-3) demonstrates the equation for compartment j

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$$\frac{dN_j^i}{dt} = S_j^i - \lambda_{j,j}^i N_j^i + \sum_{k=1,k\neq j}^{n} \lambda_{j,k}^i N_k^i \quad (4\text{-}3)$$

where

S_j^i = the release rate of species i in compartment j in atoms/s
$\lambda_{j,j}^i$ = the removal rate of species i within compartment j in 1/s
N_j^i = the inventory of species i in compartment j in atoms
$\lambda_{j,k}^i$ = the transfer rate of species i from compartment j to compartment k in 1/s
N_k^i = the inventory of species i in compartment k in atoms.

A matrix formulation can be used to represent the above equations for n compartments as shown in Equation (4-4)

$$\begin{pmatrix} \dot{N}_1^i \\ \dot{N}_2^i \\ \dot{N}_3^i \\ \vdots \\ \dot{N}_n^i \end{pmatrix} = \begin{pmatrix} -\lambda_{1,1}^i & \lambda_{1,2}^i & \lambda_{1,3}^i & \dots & \lambda_{1,n}^i \\ \lambda_{2,1}^i & -\lambda_{2,2}^i & \lambda_{2,3}^i & \dots & \lambda_{2,n}^i \\ \lambda_{3,1}^i & \lambda_{3,2}^i & \ddots & \dots & \lambda_{3,n}^i \\ \vdots & \vdots & \vdots & \dots & \vdots \\ \lambda_{n,1}^i & \lambda_{n,2}^i & \lambda_{n,3}^i & \dots & -\lambda_{n,n}^i \end{pmatrix} \begin{pmatrix} N_1^i \\ N_2^i \\ N_3^i \\ \vdots \\ N_n^i \end{pmatrix} + \begin{pmatrix} S_1^i \\ S_2^i \\ S_3^i \\ \vdots \\ S_n^i \end{pmatrix} \quad (4\text{-}4)$$

Note that the time derivative is represented by $\dot{N}_j^i$. The λ coefficient matrix is a transfer matrix where the diagonal terms are the removal coefficients applicable to a given compartment j (hence the – sign) and the off-diagonal terms are transfer coefficients relating the transfer of material from various compartments to compartment j.

Off-diagonal transfer terms are calculated as f/V where f is the flow rate out of a compartment (volume units/s) and V is the compartment volume, yielding units of 1/s. This ratio is multiplied by the radionuclide inventory in the upstream connecting compartment to provide a source to the connecting downstream compartment. Diagonal terms or removal terms are more complex because of the various removal processes that are modeled in the RADTRAD-AC. However, the idea is the same in that a removal coefficient expressed in units of 1/s is multiplied by the radionuclide inventory to yield a removal rate. Details on the calculation of removal coefficients are provided in Section 4.5.

Equation (4-4) is solved in the RADTRAD-AC using a matrix exponential based on work done in reference [11]. Matrix exponential methods are used to solve systems of linear differential equations of the form $X = AX + S$ subject to an initial condition X_0.

Note that radionuclide decay is not explicitly included in Equation (4-4). Rather, decay is accounted for in the RADTRAD-AC by dividing the solution of the differential equations into two parts: (1) radioactive decay and daughter in-growth, and (2) radionuclide transport. Inclusion of radioactive decay and daughter in-growth modeling with Equation (4-4) significantly increases

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the size of the linear system as well as the computational load to solve the system, and the separation of these calculations was used to overcome the limitations of personal computers available at the time the original version of the RADTRAD-AC was developed and has been retained to the present time.

The decay and transport calculations are performed alternately. That is, the code begins its integration over a time step by analyzing the effect of radioactive decay and daughter in-growth on the inventory of all compartments. After updating the inventory, the code calculates the effect of radionuclide transport between compartments during that same time step. This process of alternating between radioactive decay and daughter in-growth and radionuclide transport continues until the specified end time is reached. In calculations where radioactive decay is not modeled, the solution algorithm is simplified to the single step of calculating radionuclide transport.

During the course of its numerical integration, the code keeps track of the quantity of each nuclide at each location. Locations include not only compartment volumes, but surfaces and filters as well. By tracking the radionuclides in this manner, conservation of mass can be verified.

The analytical solution of a matrix equation in the form $\dot{N} = AN + S$ is $N(t) = N(0)e^{At} - A^{-1}(e^{At} + I)S$ from Equation 3.7 and 3.8 of reference [11], can be confirmed by substituting the solution into the matrix equation. Numerical solution of the transport equations is accomplished by constructing the solution as a Taylor series expansion of the analytical matric exponential solution in terms of t (specifically the e^{At} term which is the only time dependent term) and truncating the series when the estimated relative error is less than 1E-08. One advantage of this approach is its capacity to obtain good solutions over large time intervals. The key assumption is that there is no change in any phenomenon during a time step, i.e., that the coefficients in the ordinary differential equations (ODEs) are constant.

Without this assumption, the method would not apply. In order to accommodate this assumption, the code synchronizes time steps with the user-supplied phenomena in order to capture changes in the coefficients. Another advantage of this approach is that it is very fast and extremely robust. The algorithm is essentially identical to the one described in reference [11]. A useful discussion of matrix exponential methods and how they are solved is given in reference [12].

The assumption that all nuclides can be grouped according to their chemical and transport similarities is also applied in the solution. Thus, four transport groups were used: noble gases, elemental iodine, organic iodine, and aerosols. Note that the aerosol transport group includes all radionuclides assumed to be aerosol as listed in Section 4.3. These transport groups interact with their surroundings differently, but all components of any one group act the same. This implies that all xenon and krypton isotopes will transport identically and that cesium,

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barium, and all other aerosol isotopes will transport identically. The user specifies the fractions for the released iodine and thus partitions the iodine within the latter three groups.

4.2 Adaptive Time Step Algorithm

The RADTRAD-AC includes a default algorithm for selecting time step size that is fast and has proven to produce good results for typical models. However, the default time step algorithm does not perform error checking to verify that a solution has converged. The *Adaptive Time Step* option increases the computational cost significantly, but allows the RADTRAD-AC to estimate error and adjust the time step size keeping the error within a specified limit. For many models, the *Adaptive Time Step* option will not change results significantly because the default time step algorithm is adequate to achieve convergence.

As discussed above, a single system of coupled ODEs that simultaneously represents all of the phenomena considered by the RADTRAD-AC is defined. Computation time can be reduced by dividing the calculations into two parts: (1) transport and (2) radioactive decay. The fundamental premise behind this approach is that during a time step of small enough duration, ignoring the interdependence of the two components of the calculations results in negligible error. That is, numerically solving the transport equations defining transfer of material between compartments during a time step can be solved numerically, without taking account of the radioactive decay and in-growth occurring over that period, will have a negligible impact on the transport solution. Likewise, solving the radioactive decay and in-growth equations during a time step, without considering the simultaneous phenomenon of transport between compartments, will have a negligible impact on the decay and in- growth results. Reducing the time step size reduces the error that results from separately calculating transport and radioactive decay, and the RADTRAD-AC automatically reduces the default time step size when decay is active. If the user is concerned with this approach, adaptive time step control can be enabled to assure that the error introduced by this assumption is small.

The purpose of an adaptive time step algorithm is to actively choose the time step size in order to keep the solution error below a specified limit. The exact error is not known, so error must be estimated. The error estimate is then used to decide if the time step is too large (or too small) and adjust the time step size accordingly. The adaptive time step algorithm involves the following steps:

1. The error is estimated at each time step by calculating two solutions for the next time step, with one solution being more accurate. The magnitude of the difference between the solutions is used to estimate the error. The ranges from 0 if there is no error to a maximum error of 1. The error is scaled in order to reduce the number of time steps taken in regions where the solution is not changing significantly. The scaled error is also limited to the range 0 to 1.

2. The scaled error is compared to the user specified maximum error and the following steps are taken depending on the magnitude of the error:

    a. If the error value is above the maximum error value (0.001 by default but can be set by the user), then the time step size is cut in half and the calculation is repeated.
    b. If the error value is between the maximum error and 1/10 the maximum error, the time step size is kept.
    c. If the error is below 1/10 the maximum error the time step size is doubled starting with the next time step.

This algorithm works as long as error decreases as the time step size decreases and the time step size stay above the minimum time step size. Modifications to this logic to address special cases are discussed later in this section.

The governing equations for the RADTRAD-AC are defined and solved in terms of the radionuclide inventory (atoms) in each compartment. The key results; however, are the dose to hypothetical individuals located at specified locations. The dose values were used in calculating an error estimate because the dose quantities are the primary values of interest and because the dose values are included in the plot file which makes it easier to understand the adaptive time step controller behavior and diagnose problems.

The ODE solves for $N_{n,i}(t_m)$, which is the number or atoms of nuclide n in compartment i at time t_m (the time at time step m). The dose calculations are represented by $D_{k,n}(t_m)$ which is the dose in compartment i of category k for nuclide n at time t_m. The different categories (k) of dose that are calculated include cloudshine, inhalation, skin, thyroid, and TEDE. To estimate the error at each time step m, two solutions are calculated for time $t_{m+1} = t_m + \Delta t$ starting from the base solution point $N_{n,i}(t_m)$, with associated dose represented as D_B (dose at the base point):

1. The first solution at time t_{m+1} is calculated by advancing the ODE solver by a full time step of size Δt. The associated dose is represented as D_{S1} (dose for solution 1).

2. The second solution for time t_{m+1} is calculated by advancing the ODE solver by two half time steps (i.e. time steps of size $\Delta t/2$). The associated dose is represented as D_{S2} (dose for solution 2).

Note that D_B, D_{S1}, and D_{S2} can be considered vectors where the elements of the vector are in units of dose. In order to estimate the error, it is useful to define a measure of magnitude for the dose vector. The most obvious choice is the Euclidean length, which gives an overall measure of the magnitude of the dose vector. The magnitude (or norm) of the dose vector will be represented as $\|D_i\|$.

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To estimate the local error, the magnitude of the difference between the two solutions $//D_{S2} - D_{S1}//$ is compared to the magnitude of the change in the solution over the time step. The magnitude of the change in the dose over the current time step for solution 1 and 2 is $//D_{S1} - D_B//$ and $//D_{S2} - D_B//$ respectively. To characterize the change in the magnitude, the two values are averaged ($(//D_{S1} - D_B// + //D_{S2} - D_B//)/2$. A slightly modified version of the following formula is used in Equation (4-5) to calculate the error:

$$error = \frac{2\,//D_{S2} - D_{S1}//}{//D_{S1} - D_B// + //D_{S2} - D_B//} \tag{4-5}$$

If we consider than the points D_B, D_{S1}, and D_{S2} form a triangle, and that the local error above is just the magnitude (or length) of one side of the triangle compared to the average magnitude of the two remaining sides, it can be shown that the range of values for the local error is 0 to 2. A value of 0 occurs if the solutions D_{S1} and D_{S2} are identical, in which case the numerator is 0. The range 0 to 1 seems to be a more natural choice for specifying an allowable error fraction, so the local error equation was modified slightly by dropping the factor of 2, resulting in Equation (4-6) for local error:

$$local\ error = \frac{//D_{S2} - D_{S1}//}{//D_{S1} - D_B// + //D_{S2} - D_B//} \tag{4-6}$$

To provide an example of how Equation (4-6) works, error will be calculated for a set of two nuclides (I-131 and I-132). Table 4-1 represents the values for I-131 and I-32 at the base step and after solution 1 and solution 2 are calculated.

Table 4-1 Local error solutions for I-131 and I-132

Solution Step	I-131 Dose (rem)	I-132 Dose (rem)	Magnitude $(I\text{-}131^2 + I\text{-}132^2)^{0.5}$ (rem)
D_B (20 hrs)	0.75	0.00130	
D_{S1} (24 hrs)	0.92	0.00153	
D_{S2} (24 hrs)	0.90	0.00150	
$D_{S1} - D_B$	0.17	0.00023	0.17000016
$D_{S2} - D_B$	0.15	0.0002	0.15000013
$D_{S1} - D_{S2}$	0.02	0.00003	0.020000002

Note that the change in the dose value over the time step of 0.17 for I-131 is much larger than the change in the dose value of 0.00023 for I-132. This is reflected in the magnitude of the dose vector since the value is very close to the I-131 value of 0.17 rem. In the error calculation below the small tail value is dropped. In general, it is the dose channels with the largest change in

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dose over a time step that dominates the error calculation. Over this time step, the local error is calculated by Equation (4-7).

$$local\ error = \frac{0.02}{(0.17 + 0.15)} = 0.0625 \tag{4-7}$$

The default threshold for error is 0.001, so the local error exceeds the default threshold by an order of magnitude.

In the RADTRAD-AC, there are several different arrays that store different sets of dose information. There are arrays for cloudshine, inhalation (which includes whole body and thyroid), and skin which include the different nuclide dose totals. Another set of dose arrays include the accumulated dose for skin, thyroid, whole body, and TEDE. A separate error is calculated for each of these arrays, and the largest of these is recorded as the error.

In test simulations it was found that the RADTRAD-AC required very small time steps to limit error despite the fact that the rate of dose increase was very small over the first few seconds in these cases. In order to avoid taking an excessive number of time steps over a time period when the changes in dose were small, the error is scaled in proportion to how quickly the dose is increasing compared to a more global measure of the rate of change in dose.

An error scaling factor is calculated using the following steps:

1. The local rate of change for the dose is characterized by taking the change in dose (rem) over the time step (i.e. $||D_{S2} - D_B||$) and dividing this by the time step size Δt. This gives a local rate of change $d||D||/dt$.

2. Two more global rate of change values are then calculated:

    a. One global estimate of $d||D||/dt$ is calculated by taking a time step of the default time step size. The error may be large for this time step, but the rate of change in dose provides a general estimate of how rapidly the dose is expected to increase over time steps of the default size. The calculation is only performed over the first 1/10 of the simulation because early on, this is the best estimate that can be obtained of the rate of change in dose. Later in the simulation, the calculated dose provides a reasonable estimate.
    b. The value $d||D|| = ||D_{S2} - D_B||$ is integrated (i.e. summed over the time steps) and divided by the total simulation time DT. This basically gives a rate at which dose would have to increase over the whole simulation to get the current dose magnitude.

3. The scaling factor is calculated by dividing the local rate of change by the maximum of the two global rate estimates from step 2. If the local dose is changing at a very slow rate compared to the global measure, then the error is of less concern since the error is

small in comparison to time when dose is increasing rapidly. If the scaling factor exceeds 1, it is set to 1.

4. The scaled error is calculated by multiplying the error by the scaling factor. The scaled error can then be used to decide if the time step size needs to be cut, held constant, or increased.

In some cases, it may be desirable to directly control the time step size even if the adaptive time step algorithm is used. This can be done by specifying a time step table with the minimum and maximum time step size to the same value. This will override the adaptive time step algorithm.

In test cases, it was found that the reported error was always large over the first few time steps. To stabilize the simulation, a few time steps are taken at the minimum time step size. The adaptive time step logic is interrupted occasionally over the first 1/10 of the simulation to take a step of the default size in order to calculate a scaling factor. In some cases the error may increase as the time step size is decreased due to round off error or due to instability of the numerical algorithm (which can happen if the time step size is too large). The adaptive time step algorithm tracks the error vs. time step size. If it detects a region where the error increases as the time step size decreases, the algorithm just uses a default time step for a few steps and returns control to the adaptive time step logic. In some cases the adaptive time step algorithm cuts the time step until the minimum time step size is reached. The adaptive time stepper will count how many steps it remains at the minimum time step size. If more than a few time steps are taken at the minimum time step, a time step of the default size is requested. This approach is used to keep the adaptive time algorithm from performing calculations for long periods at the minimum time step size.

4.3 Radionuclide Release Mechanisms

A large number of radionuclides in various chemical forms are generated in the fuel as the reactor operates. The nuclides which are generated are categorized into chemical groups in order to make the problem more tractable. Table 4-2 lists the chemical grouping used in SNAP/RADTRAD. Note that the chemical grouping was revised from RADTRAD version 3.03 because of the addition of the ICRP-38 [5] nuclide set by combining strontium and barium into a single group and adding the other chemical elements as Group 9. Since SNAP/RADTRAD treats all nuclides that are in Groups 3 and above as aerosols, there was no internal coding changes needed. A representative nuclide is used to identify each chemical group. The tenth group for non-radioactive aerosols is retained in SNAP/RADTRAD.

Table 4-2 Chemical element grouping for SNAP/RADTRAD

Group Number	Group Name	RG 1.183 Chemical	Additional Nuclides

		Grouping	
1	Noble Gases	Kr, Xe	H *(H-3)*, Ne, Ar, Rn, N, O
2	Halogens	I	Br
3	Alkali Metals	Cs, Rb	
4	Tellurium Group	Te, Sb	Se
5	Barium, Strontium (Alkaline Earth Metals)	Sr, Ba	Sr, Ba
6	Noble Metals	Ru, Rh, Mo, Tc, Co	Pd
7	Cerium Group	Ce, Pu, Np	
8	Lanthanides	La, Zr, Nd, Nb, Pr, Y, Cm, Am	Eu, Pm, Sm
9	Others		Ac, Ag, Al, As, At, Au, Be, Bi, Bk, C, Ca, Cd, Cf, Cl, Cr, Cu, Dy, Er, Es, F, Fe, Fm, Fr, Ga, Gd, Ge, Hf, Hg, Ho, In, Ir, K, Lu, Md, Mg, Mn, Na, Ni, Os, P, Pa, Pb, Po, Pt, Ra, Re, S, Sc, Si, Sn, Ta, Tb, Th, Ti, Tl, Tm, U, V, W, Yb, Zn
10	Non-Radioactive Aerosols	No change	F, Cl[a]
a. F and Cl (halogens) are included in the group 10 since they likely do not behave like iodine.			

The iodine group is further subdivided into three physical forms, which are elemental, organic and aerosols. The fraction of each form depends on the source term model used. The radionuclide inventory for the fuel for all radionuclides of interest in dose analysis on a per MWth basis for PWR and BWR plants is included in SNAP/RADTRAD.

Two models available in SNAP/RADTRAD in which to model the release from the fuel are the TID-14844 model and the NUREG-1465 model. The TID-14844 model, which is generally applied to LOCA analysis, is based on the assumption that 100 percent of the noble gas radionuclides and 50 percent of the iodine radionuclides are available for release to the containment. The iodine release is reduced by a factor of 2 to account for deposition within the containment so that 25 percent of the iodine remains airborne in the containment based on the assumptions in Regulatory Guide 1.3 (RG 1.3), "Assumptions used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accidents for Boiling Water Reactors," [13] and Regulatory Guide 1.4 (RG 1.4), "Assumptions used for evaluating the Potential Radiological Consequences of a Loss of Coolant Accidents for Pressurized Water Reactors" [14]. No adjustment is made for the noble gases since radionuclides in this group are inert. The release is assumed to be instantaneous (a puff release) and is assumed to occur at the beginning of the accident (t=0). The fractions for the physical form of iodine used in the TID-14844 model are: elemental – 0.91, organic – 0.04 and aerosol – 0.05.

An alternative release model was developed in NUREG-1465 for LOCA analysis that considered the results of severe accident research conducted by the NRC. In this model, the

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release from the fuel is subdivided into the Gap release and the Early In-vessel release. Radionuclides that have accumulated in the gap between the fuel pellet and the cladding that is released when cladding failure commences is the Gap release. The Early In-vessel release occurs as fuel rod temperatures increase driving the volatile nuclides, such as iodine from the fuel pellet into the vessel through the failed cladding. The release fractions for the Gap and Early In-vessel releases are summarized below:

- Noble gases – 0.05 for the Gap release and 0.95 for the Early In-vessel releases.
- Iodine – 0.05 for the Gap release for both PWR and BWR. For Early In-vessel, the iodine release fraction is 0.35 for PWR and 0.25 for BWR.
- Cesium – 0.05 for the Gap release for both PWR and BWR. For Early In-vessel, the cesium release fraction is 0.25 for PWR and 0.2 for BWR.
- Remaining groups – 0.02 and less.

The fractions for the physical form of iodine used in the NUREG-1465 model are: elemental – 0.0485, organic – 0.0015 and aerosol – 0.95.

Release phase duration is considered in NUREG-1465 in contrast to the instantaneous release model used in TID-14844. The release phase durations from Table 3-6 of NUREG-1465 are listed in Table 4-3. Additionally, the radionuclides for each phase are assumed to be uniformly released over the time period corresponding to that phase.

Table 4-3 Release phase durations for PWRs and BWRs

Release Phase	Duration (hours)	
	PWR	BWR
Gap	0.5	0.5
Early In-Vessel	1.3	1.5

Note that Gap release fraction models are available in SNAP/RADTRAD. The two models which are available are based on RG 1.183 and Regulatory Guide 1.25 (RG 1.25), "Assumptions Used for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors," [15]. The release fractions used are listed in Table 4-4.

Table 4-4 Gap release fractions used in SNAP/RADTRAD

Radionuclide	RG 1.25	RG 1.183
I-131	0.12	0.08

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Kr-85	0.3	0.1
Other Noble Gases	0.1	0.05
Other Iodines	0.1	0.05
Alkali Metals	0.0	0.12

Models for specifying the release during a FHA, a REA, and CRDA have also been incorporated into SNAP/RADTRAD. The models follow those specified in RG 1.183. For the FHA, the user-selectable Gap release fractions are based on either RG 1.25 or RG 1.183 as listed in Table 4-4. In addition, relevant plant parameters (number of rods in the core, number of rods damaged, radial peaking factor, pool iodine decontamination factor and decay period) for modeling a FHA can be specified by the user. Similarly, for the REA-CRDA, a release model based on RG 1.183 is available in SNAP/RADTRAD. The release fractions used are listed in Table 4-5. Also, the relevant plant parameters for cladding breach, fuel melt fraction and radial peaking factor can be set by the user in SNAP/RADTRAD.

Table 4-5 SNAP/RADTRAD release fractions for an REA-CRDA accident

Radionuclide	Gap Release	Melt Release
Noble Gas	1.0	1.0
Iodine	0.1	0.5
Alkali Metals	0.0	0.0

It should be noted that the release assumptions used in SNAP/RADTRAD can be confirmed through the SNAP Model Editor by defining a source, then reviewing the nuclide definitions for that source. This approach is better because the user can confirm the values actually used in the SNAP/RADTRAD calculations.

4.4 Reactor Coolant System Activity Calculations

The ability to calculate the RCS activity, consider equilibrium activities based on DE I-131 and DE Xe-133, and iodine spiking has been incorporated into SNAP/RADTRAD.

The RCS concentrations are determined using formulations based on the NUREG-0017, Revision 1, “Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized Water Reactors (PWR-GALE Code),” [16], NUREG-0016, Revision 1, “Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Boiling Water Reactors (BWR-GALE Code),” [17], and the ANSI/ANS-18.1-1999, “Radioactive Source Term for Normal Operation of Light Water Reactors,” [18]. The formulations used are basically correlations correcting for plant-to-plant variations in power, system fluid and steam mass and

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flow rates and other plant-specific parameters applied to a reference PWR or BWR plant. The calculations performed are similar to, but basically a subset of those performed the PWR and BWR Gale codes.

Table 4-6 presents the formulae used for the reference PWR plant to calculate coolant concentration adjustment factors for the radionuclide concentration in the RCS. Note that these formulations are applicable to plants with U-tube steam generators. The adjustment factors presented in Table 4-6 are multiplied by the reference PWR radionuclide concentrations given in Table 4-7 to obtain the RCS concentration (μCi/g).

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Table 4-6 Formulations used to determine RCS water radionuclide concentrations in PWRs with U-tube steam generators

Element Class	Adjustment Factor Formula
Noble Gases	$= \left(\frac{162 \cdot P}{WP}\right) \cdot \left(\frac{0.009 + \lambda}{R + \lambda}\right)$
Halogens	$= \left(\frac{162 \cdot P}{WP}\right) \cdot \left(\frac{0.067 + \lambda}{R + \lambda}\right)$
Cs, Rb	$= \left(\frac{162 \cdot P}{WP}\right) \cdot \left(\frac{0.041 + \lambda}{R + \lambda}\right)$
where R = the reactor coolant letdown flow in lb/hr λ = the radionuclide decay constant in 1/hr P = the core power in MWth WP = the mass of reactor coolant system water lbm	
Formulas for the removal rate (R) are presented below	
Noble Gases	$R = \frac{FB + (FD - FB) \cdot Y}{WP}$
Halogens & Cs, Rb	$R = \frac{FD \cdot NB + (1 - NB) \cdot (FB + FA \cdot NA)}{WP}$
where FD = the removal rate in the reactor coolant in 1/hr NB = the purification demineralizer DFs FB = the reactor coolant letdown flow in 1/hr FA = the flow through the purification system cation demineralizer NA = the cation demineralizer DF Y = the ratio of the total amount of noble gases routed to gaseous radwaste from the purification system to the total amount routed from the primary coolant system	

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Table 4-7 RCS radionuclide concentrations for a reference PWR plant

Radionuclide	Concentration (μCi/g)	Radionuclide	Concentration (μCi/g)
Kr-83m	0.0E+00	I-131	2.0E-03
Kr-85	4.3E-01	I-132	6.0E-02
Kr-85m	1.6E-02	I-133	2.6E-02
Kr-87	1.7E-02	I-134	1.0E-01
Kr-88	1.8E-02	I-135	5.5E-02
Xe-131m	7.3E-01	Cs-134	3.7E-05
Xe-133	2.9E-02	Cs-136	8.7E-04
Xe-133m	7.0E-02	Cs-137	5.3E-05
Xe-135	6.7E-02	Rb-86	0.0E+00
Xe-135m	1.3E-01	Cs-134	3.7E-05
Xe-138	6.1E-02		

Table 4-8 presents the formulae used for the reference BWR plant to calculate coolant concentration adjustment factors for the radionuclide concentration in the RCS water and steam. The adjustment factors presented in Table 4-8 are multiplied by the reference BWR radionuclide concentrations given in Table 4-9 to obtain the RCS concentration (μCi/g) for either the RCS water or steam.

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Table 4-8 Formulations used to determine RCS water radionuclide concentrations in BWRs

Element Class	Adjustment Factor Formula
Noble Gases	1.0
Halogens	$= \left(\frac{112 \cdot P}{WP}\right) \cdot \left(\frac{1.01 + \lambda}{R + \lambda}\right)$
Cs, Rb	$= \left(\frac{112 \cdot P}{WP}\right) \cdot \left(\frac{0.19 + \lambda}{R + \lambda}\right)$
where R = the reactor coolant letdown flow in lb/hr λ = the radionuclide decay constant in 1/hr P = the core power in MWth WP = the mass of RCS water lbm	
Formulas for the removal rate (R) are presented below	
Noble Gases	1.0
Halogens & Cs, Rb	$R = \frac{FA \cdot NA + NC \cdot FS \cdot NS \cdot NB}{WP}$
where FA = the water cleanup demineralizer flow rate in lb/hr NA = the reactor water cleanup demineralizer DFs NC = the ratio of condensate demineralizer flow rate to steam flow rate FS = the steam flow rate in lb/hr NS = the ratio of radionuclide concentration in reactor steam to the concentration in reactor water NB = the condensate demineralizer DF	

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Table 4-9 RCS radionuclide concentrations for a reference BWR plant

Radionuclide	Liquid Concentration (µCi/g)	Steam Concentration (µCi/g)	Radionuclide	Liquid Concentration (µCi/g)	Steam Concentration (µCi/g)
Kr-83m	0.0E+00	5.9E-04	I-131	2.2E-03	4.4E-05
Kr-85	0.0E+00	4.0E-06	I-132	2.2E-02	4.4E-04
Kr-85m	0.0E+00	1.0E-03	I-133	1.5E-02	3.0E-04
Kr-87	0.0E+00	3.3E-03	I-134	4.3E-02	8.6E-04
Kr-88	0.0E+00	3.3E-03	I-135	2.2E-02	4.4E-04
Xe-131m	0.0E+00	3.3E-06	Cs-134	3.0E-05	3.0E-08
Xe-133	0.0E+00	1.4E-03	Cs-136	2.0E-05	2.0E-08
Xe-133m	0.0E+00	4.9E-05	Cs-137	8.0E-05	8.0E-08
Xe-135	0.0E+00	3.8E-03	Rb-86	0.0E+00	0.0E+00
Xe-135m	0.0E+00	4.4E-03			
Xe-138	0.0E+00	1.5E-02			

T/S equilibrium activity based on DE I-131 and DE Xe-133 are determined from the DCFs and the RCS concentration. Equations (4-8) and (4-9) show the formulation used

$$DE\ I\ 131 = \frac{\sum_i C_i \cdot DCF_i}{DCF_{I\ 131}} \tag{4-8}$$

$$DE\ Xe\ 133 = \frac{\sum_i C_i \cdot DCF_i}{DCF_{Xe\ 133}} \tag{4-9}$$

where

DCF = the DCF for each iodine or xenon nuclide. The thyroid DCF (Sieverts (Sv)/Becquerels (Bq)) is used for iodine nuclides and the whole body DCF (Sv-m^3/Bq-s) is used for xenon nuclides.

C_i = the i-th radionuclide concentration in µCi/g.

The actual equilibrium factor is calculated from the user-specified value of DE I-131 (typically 1 µCi/g) divided by DE I-131. This factor is multiplied by the RCS activity to obtain the equilibrium activity based on DE I-131. The approach is the same for Xe-133 except that Xe-133 factors are applied. The calculation is performed separately for liquid and steam in BWRs.

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The pre-incident spike activity is computed from the user-specified spike activity (typically 60 μCi/g) divided by DE I-131 and then multiplied by the RCS activity. The calculation is performed separately for liquid and steam in BWRs.

Co-incident spiking is somewhat more complicated as the iodine appearance rate must be determined. The appearance factor in units of Ci/h is computed as shown in Equation (4-10)

$$AF = \left(MLD \cdot \frac{1 - 1/DF}{WP} + \frac{LRCS}{WP} \right) \cdot SpM \cdot \left(\frac{3600}{1E6} \right) \cdot WP \cdot EFI \quad (4\text{-}10)$$

where

MLD = the normal letdown flow rate in gpm (converted to g/s in above equation)
DF = the mixed bed demineralizer DF
WP = the mass of RCS T/S leakage rate in gpm (converted to g/s in above equation)
λ = the decay constant in 1/s
SpM = the iodine spike multiplier
EFI = the equilibrium factor for iodine in μCi/g.

The total iodine appearance for co-incident spiking is computed by multiplying the appearance rate by the spike duration in hours to obtain the total iodine appearance. The iodine appearance is added to the equilibrium activity to obtain the total RCS activity for iodine. Note that co-incident spiking only applies to PWRs.

One item that should be noted is that there are several formulations for the calculation of the RCS inventory, including ANSI/ANS-18.1-1999, the PWR-GALE Code and the BWR-GALE Code. The current status of ANSI/ANS-18.1-1999 is that it is withdrawn because there has been no update for 10 years. The NRC is considering sponsoring an update to ANSI/ANS-18.1-1999 to make it current at the time this manual was prepared.

4.5 Removal Models

Models for radionuclide removal from the compartment atmosphere including sprays, natural deposition, leakage, and filters are included in SNAP/RADTRAD. The removal coefficients for the various removal mechanisms are equivalent. For example, filtration is expressed in terms of efficiencies, and natural deposition in terms of removal coefficients. These are related to each other as well as to DFs. The DF is defined as the ratio of the total aerosol material subjected to a removal process to the total aerosol material that remains airborne. Equation (4-11) shows the relationship between the DF and the removal coefficient, λ.

$$\frac{dDF}{dt} = \lambda DF \quad (4\text{-}11)$$

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The average DF is related to the mass fraction, m_f, remaining in the volume as shown in Equation (4-12).

$$m_f = \frac{M(t)}{M(0)} = \frac{1}{DF} = e^{-(\lambda t)} \quad (4\text{-}12)$$

The DF is also related to the removal efficiency, η, as shown in Equation (4-13).

$$DF = \frac{1}{1-\eta} \quad (4\text{-}13)$$

4.5.1 Spray Removal Model

The spray removal mechanism in SNAP/RADTRAD can be modeled using either the Powers' model, as described in NUREG/CR-5966, "A Simplified Model of Aerosol Removal by Containment Sprays," [19], for aerosol removal or through the specification of user-defined removal coefficients. As the Powers' model is only applicable to aerosols, the SNAP/RADTRAD user will still need to specify removal coefficients for elemental and organic iodine.

The extent to which sprays will decontaminate an aerosol-laden atmosphere depends on the number of spray droplets falling through the atmosphere and the distance they fall. The water flux into the containment atmosphere is time dependent and the fall distance is dependent upon the containment design. The Powers' model is based on a correlation that determines the removal coefficient for an aerosol considering the spray water flux, W ($m^3 \cdot H_2O/m^2 \cdot s$) and the fall height of the spray droplets $H(m)$ and considers uncertainty in the various parameters affecting spray removal. Since the model was developed from an uncertainty study, the user specifies a percentile. The "best estimate" value is associated with the 50th percentile, or median values; the lower bound is associated with the 10th percentile; and the reasonable upper bound, or largest DF, with the 90th percentile. The model was developed using values of 0.001, 0.1 and 0.25 cm^3 H_2O/cm^2 s for the spray water flux, W, and fall heights of 500, 853, 1000, 1584, 2000, 3000, 4000, and 5000 cm. The aerosol removal coefficient is dependent on the fraction of the aerosol suspended in the atmosphere, m_f, which is defined as the aerosol mass in the atmosphere of a compartment at a given time, t, divided by the total aerosol mass released into the compartment atmosphere until this time. The model includes the effect of the unsprayed portions of the containment by incorporating the assumption that the circulation in the compartment is rapid compared with the removal rate. Equation (4-14) specifies the aerosol removal coefficient (λ) at any time.

$$\lambda(s^{-1}) = \frac{1}{3600(1+\alpha)}\left(\left(a + b\log^{10} W\right)\left\{1 - \left[\frac{m_f(t)}{0.9}\right]^c\right\} + \left(\frac{m_f(t)}{0.9}\right)^c\right)$$
$$\exp\left(A + B\ln W + C H + D W^2 H + E WH^2 + F W + G W^2 H^2\right) \quad (4\text{-}14)$$

The definitions for the constants A, B, C, D, E, F, G, a, b, and c in Table 4-10 are from Section 7 of NUREG/CR-5966. The parameter α is the ratio of the compartment volume not exposed to sprays to the compartment volume exposed to sprays (unsprayed volume/sprayed volume). If the assumption that the circulation is rapid compared with the removal rate is not valid, then the user can split the compartment into two separate compartments and model the flow from the unsprayed portions to the sprayed portions as a convective flow. In this case α would be zero for the compartment containing the sprays.

This expression was originally developed for a puff release of aerosols into a system. In those cases where there is a continuing release, the size distribution will continually be renewed by the injected particulate. The model has been extended for this case by setting coefficients A through G to zero. This makes the model assume that the size distribution has not changed in time and that most of the material suspended is fresh material provided by the source. The aerosols removed by the sprays are collected in the sump.

Table 4-10 Values for coefficients used in the Powers' spray removal model

Constant	Value		
	10th Percentile	**50th Percentile**	**90th Percentile**
A	5.5750	6.83707	7.10927
B	0.94362	1.0074	0.92549
C	0.0	-2.4045E-05	0.0
D	-6.9821E-03	-4.1731E-03	-8.0868E-04
E	-7.327E-07	9.006E-08	0.0
F	0.0	-1.2478	0.0
G	3.555E-06	0.0	0.0
a	0.1108	0.1815	0.3751
b	-0.00201	-0.01153	0.00648
c	0.8945	0.5843	0.2786

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4.5.2 Natural Deposition Model

Natural deposition in SNAP/RADTRAD can be modeled using either Henry's correlation or Powers' model for aerosol removal due to natural deposition or through the specification of user-defined removal coefficients. As Henry's correlation and Powers' model are only applicable to aerosols, the SNAP/RADTRAD user will still need to specify removal coefficients for elemental iodine.

4.5.2.1 Henry's Correlation

The correlation developed by Henry, described in reference [20], is based upon observation of experiments concerned with aerosol decontamination. The form of Equation (4-15) is based upon the consideration that sedimentation was the dominant phenomenon observed, and the coefficients were determined from experimental data from liquid metal reactor tests.

$$\lambda = C_1 \left(\frac{h_{ref}}{h}\right)\left(\frac{\rho_P}{\rho_{P\,ref}}\right)(\rho_A)^K \tag{4-15}$$

where

h_{ref} = 5.0 m, as determined from the ABCOVE test AB5
h = the user-provided fall height in m
ρ_P = the user-provided particle density in kg/m^3
$\rho_{P\,ref}$ = the theoretical sodium oxide particle density of 2270 kg/m, as determined from the ABCOVE test AB5
ρ_A = the aerosol mass in the volume.

The coefficients that best fit the data are:

where

$\rho_A \geq 6.0\text{E}-05\ {}^{kg}/_{m^3}$ then $C_1 = 0.0220$ and $k = 0.60$

$\rho_A < 6.0\text{E}-05\ {}^{kg}/_{m^3}$ then $C_1 = 0.0016$ and $k = 0.33$.

Henry's correlation input can be modified to account for the influence of aerosol shape and moisture on the particle density by using Equation (4-16)

$$\rho_P = \alpha\rho_T + (1-\alpha)\rho_w \tag{4-16}$$

where

α = the ratio of the effective aerosol particle density to theoretical density
ρ_T = the theoretical density in kg/m^3

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ρ_w = the density of water in kg/m^3.

In many cases the aerosol has only 20 percent of its theoretical density, so that in a high steam environment its effective density would be closer to that of water. This correlation is implemented in SNAP/RADTRAD.

4.5.2.2 Powers' Model

The Powers' model for aerosol removal due to natural deposition, in NUREG/CR-6604, is based on the observation of a self-preserving aerosol size distribution as a key component in predicting aerosol behavior. Powers included the effects due to turbulence and to the multiple aerosol releases specified in NUREG-1465. The modified model was then compared with a series of CONTAIN computer code cases to verify the aging and aerosol size distributions due to the multiple sources. To account for the uncertainties, a large number of calculations were performed with the modified mechanistic model, with specific values for the type of reactor containment, reactor power, and the source term release phase, while varying the values of the uncertainty parameters. Typical uncertainty parameters were the containment pressure during the various release phases, the floor and wall surface areas, the zirconium inventory, the ratio of containment volume to thermal power, and the properties of the concrete. In all, over 20 parameters that were related to the phenomena were varied. Equation (4-17) shows the governing equation used in Powers' model

$$\frac{dDF_i(t)}{dt} = \lambda_{dep,I}(P_{th}, t)DF_i(t) \tag{4-17}$$

where

$DF_i(t)$ = the DF for the i^{th} class of radioactive aerosol at time t where i indicates the phase at which the material was released into the containment: during the Gap or Early In-vessel phases

$\lambda_{dep,I}(P_{th}, t)$ = the decontamination coefficient at time t and power P_{th} for phase I

P_{th} = the thermal power of the reactor.

The decontamination coefficient should be weighted by each chemical group release rate as was done by Powers. However, SNAP/RADTRAD does not maintain the necessary weighting factors; hence a single chemical release rate based on iodine was used for the weighting coefficients.

The decontamination coefficient, λ, was solved over the various release time intervals and for the different types of reactors and various operating power levels using a Monte-Carlo uncertainty analysis. The results of these analyses are tabulated in Tables 4-11 and 4-12, for PWRs and BWRs, and are presented in terms of percentile DFs, $\lambda_{dep}(N\%, P_{th})$. Since the model was developed from an uncertainty study, the user specifies a percentile, $N\%$. The best estimate value is associated with the 50th percentile, or median values; the lower bound is

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associated with the 10th percentile; and the reasonable upper bound, or largest DF, with the 90th percentile.

Equations (4-18), (4-19) and (4-20) determine the current decontamination coefficient, λ_{net}, from the sum of the coefficients for each phase weighted by the iodine release rate, $S_{I2,I}$, for phase I.

$$\lambda_{net} = \frac{\ln\{[DF(t+\Delta t)/DF(t)]\}}{\Delta t} \tag{4-18}$$

where

$$DF(t) = \frac{\sum_{I=1}^{4} S_{I2,I}}{\sum_{I=1}^{4} S_{I2,I} \; / \; DF_I} \tag{4-19}$$

$$DF_I = \prod_{I=1}^{4} \exp\left[\lambda_{dep,I}(N\%, P_{th})t\right] \tag{4-20}$$

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Table 4-11 Correlations of natural deposition decontamination coefficients for PWRs DBAs

Release Phase	Time Interval (s)	Correlations (hr-1)
Gap	0 – 1800 (0 – 0.5 hr)	λ_{dep} (90) = 0.0365 + 3.580E-06 P(MWt) λ_{dep} (50) = 0.0268 + 3.475E-06 P(MWt) λ_{dep} (10) = 0.0182 + 3.260E-06 P(MWt)
Gap	1800 – 6480 (0.5 – 2.0 hr)	λ_{dep} (90) = 0.1036 [1 - exp (-2.239 P(MWt)/1000)] λ_{dep} (50) = 0.0820 [1 - exp (-1.159 P(MWt)/1000)] λ_{dep} (10) = 0.0645 [1 - exp (-0.938 P(MWt)/1000)]
Early In-Vessel	1800 – 6480 (0.5 – 1.8 hr)	λ_{dep} (90) = 0.0522 [1 - exp (-2.458 P(MWt)/1000)] λ_{dep} (50) = 0.0417 [1 - exp (-1.258 P(MWt)/1000)] λ_{dep} (10) = 0.0326 [1 - exp (-0.910 P(MWt)/1000)]
Gap + Early In-Vessel	6480 – 13,680 (1.8 – 3.8 hr)	λ_{dep} (90) = 0.421 [1 - exp (-2.530 P(MWt)/1000)] λ_{dep} (50) = 0.196 [1 - exp (-1.040 P(MWt)/1000)] λ_{dep} (10) = 0.094 [I - exp (-0.869 P(MWt)/1000)]
Gap + Early In-Vessel	13,680 – 49,680 (3.8 – 13.8 hr)	λ_{dep} (90) = 0.1920 - 1.35E-06 P(MWt) λ_{dep} (50) = 0.1382 + 6.85E-06 P(MWt) λ_{dep} (10) = 0.0811 + 10.15E-06 P(MWt)
Gap + Early In-Vessel	49,680 – 80,000 (13.8 – 22.22 hr)	λ_{dep} (90) = 0.1010 λ_{dep} (50) = 0.0912 λ_{dep} (10) = 0.0860 [1 - exp (-2.384 P(MWt)/1000)]

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Table 4-12 Correlations of natural deposition decontamination coefficients for BWRs DBAs

Release Phase	Time Interval (s)	Correlations (hr-1)
Gap	0 – 1800 (0 – 0.5 hr)	λ_{dep} (90) = 2.903 [exp(-1060/P(MWt)] λ_{dep} (50) = 2.252 [exp(-1977/P(MWt)] λ_{dep} (10) = 1.285 [exp(-2199/P(MWt)]
Gap	1800 – 7200 (0.5 – 2.0 hr)	λ_{dep} (90) = 1.809 [exp(-777/P(MWt) λ_{dep} (50) = 1.722 [exp(-1777/P(MWt)] λ_{dep} (10) = 1.161 [exp(-2274/P(MWt)]
Early In-Vessel	1800 – 7200 (0.5 – 2.0 hr)	λ_{dep} (90) = 0.746 [exp(-626/P(MWt)] λ_{dep} (50) = 0.752 [exp(-1565/P(MWt)] λ_{dep} (10) = 0.520 [exp(-2173/P(MWt)]
Gap + Early In-Vessel	7200 – 18,000 (2.0 – 5.0 hr)	λ_{dep} (90) = 1.959 [exp(-548/P(MWt)] λ_{dep} (50) = 1.811 [exp(-1107/P(MWt)] λ_{dep} (10) = 1.551 [exp(-1507/P(MWt)]
Gap + Early In-Vessel	18,000 – 30,000 (5.0 – 8.33 hr)	λ_{dep} (90) = 1.533 [exp(-573/P(MWt)] λ_{dep} (50) = 1.317 [exp(-1225/P(MWt)] λ_{dep} (10) = 0.836 [exp(-1051/P(MWt)]
Gap + Early In-Vessel	30,333 – 43,200 (8.33 – 12.0 hr)	λ_{dep} (90) = 1.524 [exp(-647/P(MWt)] λ_{dep} (50) = 1.339 [exp(-1474/P(MWt)] λ_{dep} (10) = 0.780 [exp(-1316/P(MWt)]
Gap + Early In-Vessel	43,200 – 70,000 (12.0 – 19.4 hr)	λ_{dep} (90) = 1.564 [exp(-717/P(MWt)] λ_{dep} (50) = 1.373 [exp(-1634/P(MWt)] λ_{dep} (10) = 0.778 [exp(-1548/P(MWt)]
Gap + Early In-Vessel	70,000 – 86,400 (19.4 – 24.0 hr)	λ_{dep} (90) = 1.562 [exp(-719/P(MWt)] λ_{dep} (50) = 1.441 [exp(-1785/P(MWt)] λ_{dep} (10) = 0.780 [exp(-1686/P(MWt)]

Table 4-13 also provides the decontamination coefficients for a DBA in an advanced pressurized-water reactor (APWR) design. These values are based upon work by Powers, which found that the CONTAIN-related calculation results were correlated with values in the table. These correlations do not vary with reactor thermal power; hence an approximation is used when the user selects a PWR design with a different power level.

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Table 4-13 Correlations of natural deposition decontamination coefficients for APWR DBAs

Release Phase	Time Interval (s)	Correlations (hr-1)
Gap	0 – 1800 (0 – 0.5 hr)	λ_{dep} (90) = 0.466 λ_{dep} (50) = 0.233 λ_{dep} (10) = 0.029
Gap	1800 – 6480 (0.5 – 1.8 hr)	λ_{dep} (90) = 0.872 λ_{dep} (50) = 0.487 λ_{dep} (10) = 0.160
Early In-Vessel	1800 – 6480 (0.5 – 1.8 hr)	λ_{dep} (90) = 0.393 λ_{dep} (50) = 0.240 λ_{dep} (10) = 0.100
Gap + Early In-Vessel	6480 – 13,680 (1.8 – 3.8 hr)	λ_{dep} (90) = 1.210 λ_{dep} (50) = 0.980 λ_{dep} (10) = 0.731
Gap + Early In-Vessel	13,680 – 49,680 (3.8 – 13.8 hr)	λ_{dep} (90) = 0.594 λ_{dep} (50) = 0.397 λ_{dep} (10) = 0.245
Gap + Early In-Vessel	49,680 – 86,400 (13.8 – 24.0 hr)	λ_{dep} (90) = 0.598 λ_{dep} (50) = 0.327 λ_{dep} (10) = 0.107

The approximation used assumes that the significant difference between the PWR and the APWR design, in terms of natural deposition, is that the wall cooling enhances the phoretic deposition. Therefore, the difference in decontamination coefficient at 1800 MWt represents this phoretic deposition and is then scaled by the power ratio. Equation (4-21) represents the final approximation used

$$\lambda_{dep}(AP\_P_{th}) = \lambda_{dep}(PWR\_P_{th}) + \left[\lambda_{dep}(AP\_1800) - \lambda_{dep}(PWR\_1800)\right]\frac{P_{th}}{1800} \quad (4\text{-}21)$$

where

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$\lambda_{dep}(AP\_P_{th})$ = the decontamination coefficient from the APWR at the power level indicated (P_{th} =1800 or design power)

$\lambda_{dep}(PWR\_P_{th})$ = the decontamination coefficient from the PWR DBA calculation for the power level indicated (P_{th} =1800 or design power).

4.5.3 Deposition in Piping Models

At the discretion of the user, piping can be modeled as a transfer pathway where deposition can occur. A model is available for the removal of fission products during transport through pipes. Alternatively, the user may specify DFs and volumetric flow rates as a function of time. Noble gases are assumed not to interact with the piping and are transmitted without any depletion. The models chosen do not have documented limitations; however, the assumption is made that only primary deposition phenomena are being modeled. Scenarios in which supersaturated conditions occur, or in which very high or very low velocities are found, may give unrealistic results.

The models that are available in SNAP/RADTRAD for piping deposition include the Brockmann model for aerosol removal, the Bixler model for elemental iodine removal, and the Bixler model for organic iodine removal.

4.5.3.1 Brockmann Model for Aerosol Removal

The Brockmann model described in reference [21] is used to determine the amount of aerosol deposition that occurs in pipe bends and due to settling, turbulent inertia and diffusion. The mean particle diameter, d_p, used in the Brockmann model is assumed to be 1 μ with an average particle density, ρ_p, of 1000 kg/m^3. The temperature, pressure, open volume, and other parameters are provided by the user. Particles will settle due to gravitational force and deposit on the horizontally projecting lower surface of the flow path during transport. This turbulent flow deposition efficiency, η_g, is modeled in Equation (4-22)

$$\eta_g = 1 - \exp\left(-U_g A_s/\pi Q\right)$$

$$U_g = \tau g$$

$$\tau = slip \cdot d_p^2 \rho_p / 18\mu \qquad \text{(4-22)}$$

$$slip = 1.0 + 2.0\frac{mfp}{dp}\left(1.257 + 0.4e^{-0.55dp/mfp}\right)$$

where

U_g = the gravitational deposition velocity in m/s

τ = the particle relaxation time in s
Q = the user provided gas flow in m^3/s
A_s = the user provided total pipe surface area in m^2
μ = the viscosity of air, 1.93E-05 Pa-s
mfp = the particle mean free path in cm
g = the gravitational acceleration in m^2/s.

For instances of laminar flow, described in reference [22] the deposition efficiency is described by Equation (4-23)

$$\eta_g = 1 - \frac{2}{\pi}\left[2\varepsilon\sqrt{1-\varepsilon^{2/3}} - \varepsilon^{1/3}\sqrt{1-\varepsilon^{2/3}} + \arcsin\sqrt{\varepsilon^{1/3}}\right] \quad (4\text{-}23)$$

where

ε = $0.75Z - 0.75\frac{L\,U_g}{U\,D}$

and

L = the horizontal pipe length ($A_s/\pi\,D$)
A_s = the user provided total pipe surface area in m^2
D = the pipe diameter ($4 \cdot Vol/A_s$)
U_g = the gravitational deposition velocity in m/s
U = the linear velocity (Q/A_s)
Q = the user provided gas flow in m^3/s.

The laminar and turbulent settling efficiencies are equivalent for Reynolds Number between 500 and 2300.

If the flow is turbulent, then turbulence in the central core can propel a particle into the laminar sublayer. If the particle inertia is high, then it will penetrate the sublayer and be collected on the wall. There have been experiments, reference [23], on inertial deposition velocity and Brockmann has modeled the turbulent deposition efficiency, η_{turb}, as shown in Equation (4-24)

$$\eta_{turb} = 1 - \exp(-U_t A_s/Q) \quad (4\text{-}24)$$

where

U_t = $0.1988\,U_{air}/Re^{1/8}$

Re = $\rho_{air}\,U_{air}d_H/\mu$

and

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U_t = the turbulent inertial deposition velocity in m/s
U_{air} = the air velocity in m/s
d_H = the hydraulic diameter in m ($4 \cdot Vol/A_s$)
ρ_{air} = the density of air in kg/m^3.

When the flow in the pipe is slower as described in Equation (4-25), then the turbulent velocity is calculated using Equation (4-26).

$$\frac{\tau U_{air}}{d_H} Re^{3/4} < 326.3 \tag{4-25}$$

$$U_t = 1.861\text{E} - 07 \left[\frac{\tau U_{air}}{d_H}\right]^2 U_{air} Re^{11/8} \tag{4-26}$$

Small particles undergoing Brownian diffusion will diffuse from areas of high concentration to those of low concentration. Since the wall acts like a sink for these particles, there is net diffusion from the bulk to the wall. This phenomenon has been analyzed in reference [24] and the diffusional deposition efficiency is modeled as shown in Equation (4-27)

$$\eta_{diff} = 1 - \exp\left(-U_{diff} A_s / Q\right) \tag{4-27}$$

where

U_{diff} = the diffusion velocity in m/s
A_s = the user provided total pipe surface area in m^2
Q = the user provided gas flow in m^3/s.

In cases of laminar flow, this efficiency is modeled as shown in Equation (4-28)

$$\eta_{diff} = 2.56\zeta^{2/3} - 1.2\zeta - 0.177\zeta^{4/3} \tag{4-28}$$

where

ζ = the dimensionless diffusion parameter $\left(A_s D_{diff} / Q d_H\right)$

and

A_s = the user provided total pipe surface area in m^2
D_{diff} = the particle diffusion coefficient in m^2/s
Q = the user provided gas flow in m^3/s
d_H = the hydraulic diameter in m [see Equation (4-24)].

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The particle diffusion coefficient is computed as shown in Equation (4-29)

$$D_{diff} = 1.38\text{E}-16\ T_g \times \left[\frac{slip}{3\,\eta\,\mu\,dp}\right] \tag{4-29}$$

where

T_g = the gas temperature in °K.

When the flow is slow or the pipe length is large such that $\zeta > 0.02$, then the diffusional deposition efficiency is modeled as shown in Equation (4-30).

$$\eta_{diff} = 0.819\exp(-3.657\zeta) + 0.097\exp(-22.3\zeta) + 0.032\exp(-57\zeta) \tag{4-30}$$

In cases of turbulent flow, the diffusional efficiency, from reference [25], is modeled as shown in Equation (4-31)

$$\eta_{diff} = 1 - \exp\left[-\zeta^{2/3}0.0187Re^{13/24}\left(\frac{L}{d_H}\right)^{1/3}\right] \tag{4-31}$$

where

ζ = the dimensionless diffusion parameter [see Equation (4-28)]
Re = $\rho_{air}\,U_{air}d_H/\mu$ [see Equation (4-24)]
L = the path length in m $(A_s/\pi d_H)$
A_s = the user provided total pipe surface area in m^2
d_H = the hydraulic diameter in m [see Equation (4-24)].

When the direction of gas flow is diverted in a bend, an aerosol particle may deviate from the gas flow due to its inertia and deposit on the wall. The efficiency of an aerosol particle in a bend is modeled as shown in Equation (4-32)

$$\eta_{bend} = \frac{\tau U_{air}\varphi}{d_H} \tag{4-32}$$

where

τ = the particle relaxation time in s [see Equation (4-22)]
U_{air} = the air velocity in m/s
φ = the user-provided sum of the angles the flow has been diverted in radians
d_H = the hydraulic diameter in m [see Equation (4-24)].

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When the flow is turbulent, the efficiency of an aerosol particle in a bend, from reference [26], is modeled as shown in Equation (4-33).

$$\eta_{bend} = 1.0 - \exp\frac{(-2.83\ \tau\ U_{air}\ \phi)}{d_H} \tag{4-33}$$

where

τ = the particle relaxation time in s [see Equation (4-22)]
U_{air} = the air velocity in m/s
d_H = the hydraulic diameter in m [see Equation (4-24)].

In cases of laminar flow, the efficiency of an aerosol particle in a bend is modeled as shown in Equation (4-34).

$$\eta_{bend} = \left(1.0 + \left(\frac{\tau\ U_{air}}{0.171 d_H}\right)^{P_1}\right)^{-P_2} \tag{4-34}$$

where

P_1 = $0.452\left({}^{\tau\ U_{air}}/_{0.171\ d_H}\right) + 2.242$

P_2 = ${}^{2\ \phi}/_{\pi}$

Therefore, the total aerosol deposition efficiency is modeled as model as shown in Equation (4-35).

$$\eta_T = 1.0 - \left(1.0 - \eta_g\right)\left(1.0 - \eta_{turb}\right)\left(1.0 - \eta_{diff}\right)\left(1.0 - \eta_{bend}\right) \tag{4-35}$$

4.5.3.2 Bixler Model for Elemental Iodine Removal

The equation for the Bixler model for elemental iodine removal in pipes is given by Equation (4-36)

$$\eta_{ei} = 1 - \exp\left({}^{-A_S U_{ei}}/_{100Q}\right) \tag{4-36}$$

where

U_{ei} = $e^{2809/T - 12.5}$

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and

T = the gas temperature in °K.

4.5.3.3 Bixler Model for Organic Iodine Removal

The equation for the Bixler model for organic iodine removal in pipes is given by Equation (4-37) below

$$\eta_{oi} = 1 - \exp\left(-A_S U_{oi} / 100Q\right) \quad (4\text{-}37)$$

where

U_{oi} = $e^{2809/T-19.30}$

and

T = the gas temperature in °K.

4.5.4 Filters

Heating, ventilation, and air conditioning (HVAC) system filter efficiency can be input by the user for the different nuclide groups as a function of time. The filter efficiency is specified as the fraction of material passing through the filter that is trapped on the filter media. This efficiency, expressed in terms of a decontamination coefficient as shown in Equation (4-38)

$$\lambda_{filter} = \left(\eta_{filter} / 100\right) F \quad (4\text{-}38)$$

where

F = the volume-normalized flow rate in in 1/s.

4.6 Dose Analysis

Doses in the environment, within a control room, or within a given volume due to inhalation and whole body immersion can be computed in SNAP/RADTRAD. The models used are presented in the following sections and the DCFs are taken from the FGR 11 & 12.

4.6.1 Offsite Dose Analysis

The dose to an individual at the EAB and the LPZ in the environment compartment is calculated in SNAP/RADTRAD. The dose due to immersion for each nuclide, n, is calculated using Equation (4-39)

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$$D_{c,n}^{env} = A_n \left(\chi/_Q\right) DCF_{c,n} \quad (4\text{-}39)$$

where

$D_{c,n}^{env}$ = the air immersion (cloudshine) dose due to nuclide n in the environment compartment in Sv

A_n = the integrated release of nuclide n in Bq

$\left(\chi/_Q\right)$ = the user-provided atmospheric dilution factor in s/m^3

$DCF_{c,n}$ = the FGR 11 & 12 air immersion (cloudshine) DCF for nuclide n in Sv-m^3/Bq-s.

The activity is related to the number of atoms of nuclide, n, as shown in Equation (4-40)

$$A_n = \lambda_n N_n \quad (4\text{-}40)$$

where

λ_n = the radiological decay constant for nuclide n in 1/s.

The inhalation dose from each nuclide, n, is calculated using Equation (4-41)

$$D_{i,n}^{env} = A_n \left(\chi/_Q\right) BR * DCF_{c,n} \quad (4\text{-}41)$$

where

$D_{i,n}^{env}$ = the inhalation dose commitment due to nuclide n in the environment compartment in Sv

A_n = the integrated release of nuclide n in Bq

$\left(\chi/_Q\right)$ = the user-provided atmospheric dilution factor in s/m^3

BR = the user-provided breathing rate in m^3/s

$DCF_{c,n}$ = the FGR 11 & 12 inhalation DCF for nuclide n in Sv/Bq.

Note that the conversion factor of 100 Rem = 1 Sv is applied to all the dose equations to obtain the dose in units of Rem. The total dose over the entire problem time is computed as the sum of the contributions over each time interval and each nuclide.

4.6.2 Control Room Dose Analysis

The dose to an individual in a control room is calculated from the time-integrated concentration of radionuclides in the control room compartment. The dose to the individual due to air immersion in the control room calculated using Equation (4-42)

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$$D_{c,n}^{CR} = \left(\frac{DCF_{c,n}}{G_F}\right) OF \int C_n(t)dt \quad (4\text{-}42)$$

where

$D_{i,n}^{env}$ = air immersion (cloudshine) dose due to nuclide n in the control room compartment in Sv

$DCF_{c,n}$ = the FGR 11 & 12 air immersion (cloudshine) DCF for nuclide n in Sv-m^3/Bq-s

OF = the user-provided control room occupancy factor

$C_n(t)$ = the instantaneous concentration of radionuclide n in the control room

G_F = the Murphy-Campe geometric factor, given in reference [27], which is relates the dose from an infinite cloud to the dose from a cloud of volume, V, in 1/m^3. This factor is defined in Equation (4-43).

$$G_F = \frac{351.6}{V^{0.338}} \quad (4\text{-}43)$$

The inhalation dose to an individual in the control room is calculated using Equation (4-44)

$$D_{i,n}^{CR} = BR \cdot OF \cdot DCF \int C_n(t)dt \quad (4\text{-}44)$$

where

$D_{i,n}^{CR}$ = the inhalation dose commitment due to nuclide n in the control room in Sv

BR = the user-provided breathing rate in m^3/s

OF = the user-provided control room occupancy factor

$DCF_{c,n}$ = the FGR 11 & 12 inhalation DCF for nuclide n in Sv/Bq

$C_n(\tau)$ = the instantaneous concentration of radionuclide n in the control room.

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5.0 REFERENCES

[1] **NUREG/CR-6604**, “RADTRAD: A Simplified Model for RADionuclide Transport and Removal and Dose Estimation,” U.S. Nuclear Regulatory Commission, Washington, DC, December 1997.

[2] **NUREG/CR-6604**, **Supplement 1**, “RADTRAD: A Simplified Model for RADionuclide Transport and Removal and Dose Estimation,” U.S. Nuclear Regulatory Commission, Washington, DC, June 1999.

[3] **NUREG/CR-6604**, **Supplement 2**, “RADTRAD: A Simplified Model for RADionuclide Transport and Removal and Dose Estimation,” U.S. Nuclear Regulatory Commission, Washington, DC, October 2002.

[4] **SNAP Manual, Version 2.2.1**, “Symbolic Nuclear Analysis Package (SNAP) User's Manual,” Applied Programming Technology, Inc., Bloomsburg, PA, October 2012.

[5] **ICRP Publication 38**, “Radionuclide Transformations – Energy and Intensity of Emissions, International Commission on Radiological Protection, Ann. ICRP 11-13. September 1983.

[6] **EPA-520/1-88-020**, “Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion,” Federal Guidance Report No. 11, U.S. Environmental Protection Agency, Washington, DC. September 1988.

[7] **EPA-402-R-93-081**, “External Exposure to Radionuclides in Air, Water, and Soil,” Federal Guidance Report No. 12, U.S. Environmental Protection Agency, Washington, DC, September 1993.

[8] **Regulatory Guide 1.183**, “Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors,” U.S. Nuclear Regulatory Commission, Washington, DC, July 2000.

[9] **TID-14844**, “Calculation of Distance Factors for Power and Test Reactor Sites, U.S. Atomic Energy Commission, Washington, DC, March 1962.

[10] **NUREG-1465**, “Accident Source Terms for Light-Water Nuclear Power Plants,” U.S. Nuclear Regulatory Commission, Washington, DC, February 1995.

[11] Washington, K.E., “A Reflected Kinetics Model for Nuclear Space Reactor Kinetics and Control Scoping Calculations,” Texas A&M University, College Station, TX, May 1986.

Draft

[12] Birchall, A. and James, A.C., "A Microcomputer Algorithm for Solving First-Order Compartmental Models Involving Recycling," Health Physics, Vol. 56 (6), June 1989, p. 857-858.

[13] **Regulatory Guide 1.3, Revision 2**, "Assumptions used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accidents for Boiling Water Reactors," U.S. Nuclear Regulatory Commission, Washington, DC, June 1974.

[14] **Regulatory Guide 1.4, Revision 2**, "Assumptions used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accidents for Pressurized Water Reactors," U.S. Nuclear Regulatory Commission, Washington, DC, June 1974.

[15] **Regulatory Guide 1.25**, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors," U.S. Nuclear Regulatory Commission, Washington, DC, March 1972.

[16] **NUREG-0017**, **Revision 1**, "Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized Water Reactors (PWR-GALE Code)," U.S. Nuclear Regulatory Commission, Washington, DC, April 1985.

[17] **NUREG-0016**, **Revision 1**, "Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Boiling Water Reactors (BWR-GALE Code)," U.S. Nuclear Regulatory Commission, Washington, DC, January 1979.

[18] **ANSI/ANS-18.1-1999**, "Radioactive Source Term for Normal Operation of Light Water Reactors," American Nuclear Society, La Grange Park, IL, September 1999.

[19] **NUREG/CR-5966**, "A Simplified Model of Aerosol Removal by Containment Sprays," U.S. Nuclear Regulatory Commission, Washington, DC, June 1993.

[20] Fauske & Associates, Inc., "FAI Aerosol Correlation, An Industry Degraded Core Rulemaking (IDCOR) Program Report," Fauske & Associates, Inc., Bethesda, MD, 1984.

[21] Brockmann, J.E., "Sampling and Transport of Aerosols," Aerosol Measurement: Principles, Techniques, and Applications, Third Edition, John Wiley & Sons, Hoboken, NJ, September 2011.

[22] Fuchs, N.A., "The Mechanics of Aerosols," Macmillan Company, New York, NY, 1964.

[23] Liu, B.Y.H. and Agarwal, J.K., "Experimental Observation of Aerosol Deposition in Turbulent Flow," Journal of Aerosol Science, Vol. 5 (2), March 1974, p 145–148.

[24] Gormley, P.G. and Kennedy, M., "Diffusion from a Stream Flowing Through a Cylindrical Tube," Proceedings of the Royal Irish Academy, Vol. 52-A (1948 - 1950), p 163–169.

Draft

[25] Friendlander, S.K., “Smoke, Dust, and Haze: Fundamentals of Aerosol Behavior,” Wiley, New York, NY, 1977.

[26] Pui, D.Y.H., Romay-Novas, F. and Liu, B.Y.H., “Experimental Study of Particle Deposition in Bends of Circular Cross Section,” Aerosol Science and Technology, Vol. 7 (3), February 1987, p 301–315.

[27] Murphy, K.G. and Campe, K.M., “Nuclear Power Plant Control Room Ventilation System Design for Meeting General Criterion 19, 13th AEC Air Cleaning Conference,” U.S. Atomic Energy Commission, Washington, DC, August 1974.

Draft